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Managing Electric Utility Assets for the City of Aspen, Colorado

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Managing Electric Utility Assets for the City of Aspen, Colorado

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

by

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December 2018

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The report of Hamish Henderson is approved.

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Abstract

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This project describes how an electric network can be modeled in GIS. In particular it will look at the City of Aspen's electric distribution network. The City of Aspen, Colorado has a small underground electric network that has historically only been understood by a few individuals. These individuals are nearing retirement which has sparked a need for a transfer of knowledge. Over the last few years, the electric network has been slowly moved into a GIS database with a built in Geometric Network. The City of Aspen wants to move all of its utility assets, water, storm water and electric, into Esri's Utility Network. Prior to this happening, the electric network needed additional work.

This project looked at how to collect accurate electric data in the field, using Esri's Survey123 mobile application. It also describes the cleanup process for the existing data, so that it would work correctly in a Geometric Network. Finally, it explored a unique way of viewing utility assets, through an augmented reality application called AuGEO. Limitations of this augmented reality application were discovered and discussed.

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List of Acronyms and Definitions

AGOL	ArcGIS Online
AR	Augmented Reality
CAD	Computer Aided Design
COA	City of Aspen
GIS	Geographic Information Systems
GPS	Global Positioning System
TRUMA	Toms River Municipal Utility Authority
UN	Utility Network
VR	Virtual Reality

Chapter 1 – Introduction

Electricity. It's something we take for granted, but have you ever thought of where your electric power comes from? Chances are you probably haven't. Cities have miles and miles of electrical lines both above and below ground that allow you to do daily tasks like turning your coffee machine on in the morning. Private and public companies manage these electric assets to ensure that they are working and providing power to their service areas. Geographic information systems (GIS) are a great tool for managing electric utility assets. This project looked at how a small city could best manage its electric assets in a GIS format, through the help of multiple Esri software products. In particular, this project addressed how to collect data in the field, how to ensure the spatial integrity of the collected data, and also a unique way of looking at mapped data in the field.

1.1 Client

The client for this project was the City of Aspen. Aspen is located high in the Colorado Rocky Mountains about 200 miles west of Denver and 150 miles east of Grand Junction. It is a small city that is renowned for its recreational outdoor activities, but also its thriving culture that attracts visitors from around the world (About Aspen Colorado, n.d).

The direct point of contact for this project was Bridgette Kelly, the GIS Program Manager for the City of Aspen. Bridgette is responsible for overseeing and managing the GIS practices throughout the City. The client's responsibilities for the project was to provide its existing electric database and to answer technical questions related to electric networks.

1.2 Problem Statement

The City of Aspen has a small underground electric network that serves around 3,000 people within its 4 square mile service area (City of Aspen, n.d). The majority of the infrastructure was built in the 1970's and 1980's (City of Aspen, n.d). Aspen receives its electricity from a co-op electric utility company called Holy Cross Energy. Holy Cross Energy provides electric power to the surrounding counties and also areas within the Aspen city limits that are not in the city's electric service area (Holy Cross, n.d.). Aspen's electric network has historically been only fully understood by a few individuals within the electric department. In the past few years there has been a push to transfer this knowledge into a more permanent location, a GIS database.

Within the past few years, the locations of transformers and primary electrical lines have been geographically located although very few attributes were collected, such as transformer sizes and models. In 2017 a GIS Intern and Electric Line Technician collected more information on the network, including locations of secondary electrical lines, pedestals, service points and more transformer attributes. This information was loaded into a prefabricated electric geodatabase that the Esri ArcGIS Solutions team had available as part of its Electric Utility Assets Data Model (Esri, n.d.).

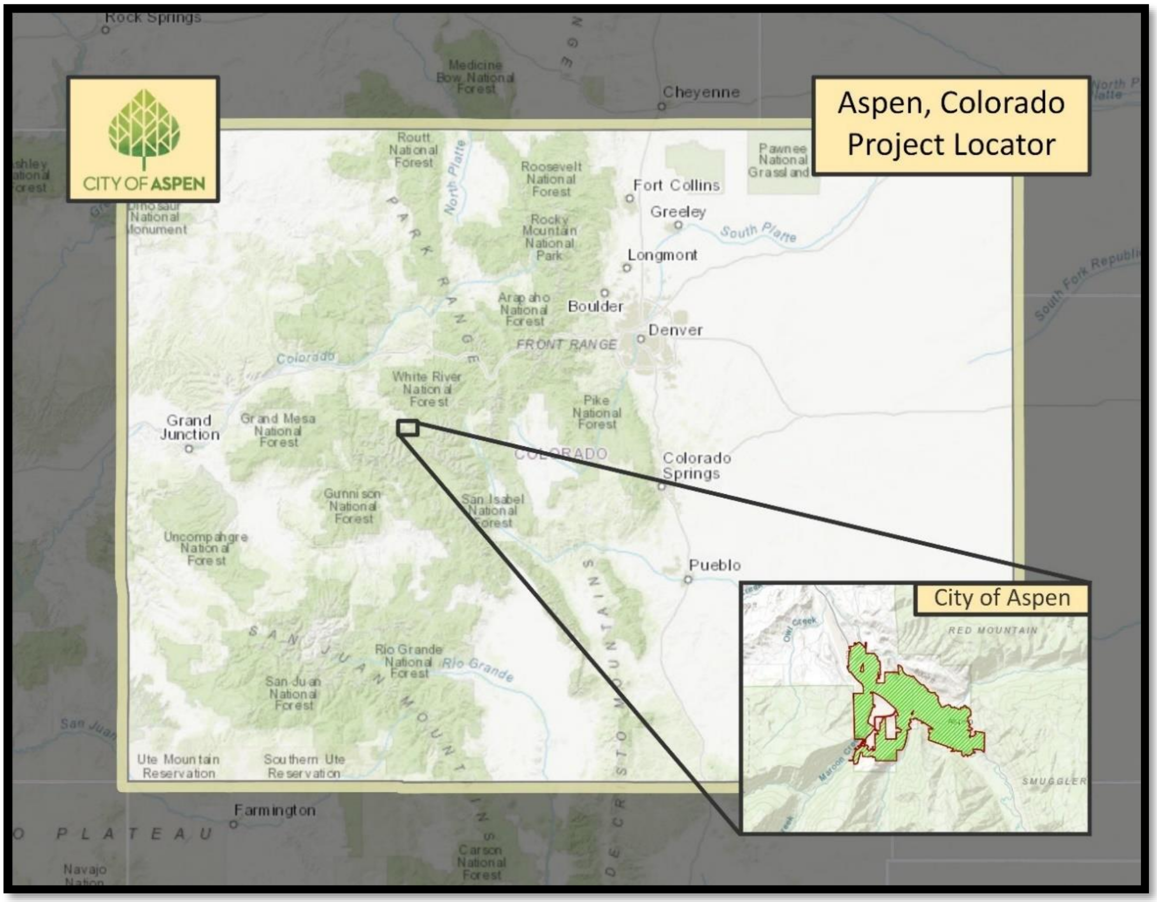

Figure 1-1: Project Location Map

This data was still lacking a lot of attribution and the electric department did not have an easy way to collect and update its own assets. Most of the field collection was done during the winter, when it was cold and often there was snow on the ground. They tried to collect data on an ArcMap project on a tablet, but due to the cold climate the tablet would often freeze and turn off, making collection difficult. To solve this issue, they went back to simpler methods of recording information on paper, and then looking at the City's high-resolution imagery to determine the correct transformer location.

In addition to lacking attribution, the data was often not correctly connected for a Geometric Network. A Geometric Network is an interconnected network of lines and points that allows for flow through a network; they have certain rules to allow for the correct direction on flow and connectivity (Esri, 2008). The City of Aspen wants to move all its utility geodatabases into Esri's new Utility Network (UN) in 2019. The UN is Esri's replacement to the geometric network and will allow for best practices of managing utility assets (Bowman, 2017). Before this migration can occur, additional data needs to be collected and the data's integrity with regards to connectivity needs to be fixed.

1.3 Proposed Solution

There are three components of this project that will help to aid the City of Aspen with its Utility Network migration. The first component is having an easy way to collect and update existing data in the field; this was done through multiple mobile applications. The data that was already collected in the field needs to be checked for quality control, this was the second portion of the project. The third portion was not necessary for the Utility Network migration but will be a helpful tool for the electric staff. It would allow the electric staff to view the electric network on a mobile device in the field.

1.3.1 Goals and Objectives

The main goal of this project was to improve the integrity of the City of Aspen's electric distribution network to allow it to be easily migrated into the new Esri Utility Network. There were three main objectives that helped accomplish this goal. The first objective for this project was to create mobile applications that the electric department could use to update and gather more information on the electric network. The second objective was to improve the integrity of the city's existing data by correcting connectivity issues throughout the distribution network. The third objective was to give the electric staff an easy way to view their assets in the field through a mobile device.

1.3.2 Scope

The three portions of this project all had separate deliverables. The field data collection portion consisted of the most individual deliverables. There was a total of eight Survey123 applications that were created. Each point feature class in the electric geodatabase had its own survey. The data clean up section had one deliverable: a geodatabase that was correctly connected and ready for migration into the Utility Network. In addition to the geodatabase, a map package was delivered that had custom made symbology. The third deliverable was an Augmented Reality (AR) mobile device application that would have allowed the electric crew to view and access utility attribution information in the field. However, this portion of the project was unsuccessful, possible reasons as to why are discussed Chapter 6.

1.3.3 Methods

The data collection applications for this project were all created using Esri's Survey123 application builder: Survey123 Connect for ArcGIS. Survey123 is an application that allows for field collection of data. To edit the existing data, the feature layers needed to be available online, therefore ArcGIS Online (AGOL) was also used for hosting the online feature services.

The data integrity and data clean up section of this project was done in ArcGIS Pro with the addition of the Data Reviewer extension. The batch rules for Data Reviewer were downloaded as part of the electric solution provided by Esri.

The AR application was created using another Esri application called AuGEO. AuGEO also required feature classes to be available online. Therefore, the necessary layers were upload to AGOL.

1.4 Audience

The audience for this project is aimed at GIS professionals and asset managers who are currently or planning to implement utility asset management into their scope of work. The project report has been written to give professionals with limited GIS knowledge the ability to understand what is happening.

1.5 Overview of the Rest of this Report

This paper has been split into seven different chapters. Chapter 2 has background information and a literature review. Chapter 3 discusses the system design and the project plan. Chapter 4 is about database design. Chapter 5 is the project implementation. Chapter 6 discuss the results from the implementation stage. Chapter 7 wraps up the paper with a conclusion and suggestions for future work.

Chapter 2 – Background and Literature Review

This chapter will discuss background information about GIS and utility asset management, focusing on electrical networks. A review of relevant literature will be incorporated.

The chapter will be broken down into three main sections. Section 2.1 will talk about the history of using GIS for utility asset management and why GIS is a good tool for it. Section 2.2 will go onto discuss different methods for collecting utility data; it will focus on mobile device collection applications. The third section, Section 2.3, will look at how organizations have incorporated Augmented Reality (AR) and utility asset management.

2.1 Utility Asset Management and GIS

According to the Oxford Dictionary, Asset Management (n.d.) is the "active management of assets in order to optimize return on investment." Originally asset management dealt with finance; how to best manage your financial assets to be profitable. Over the last few decades it has also migrated into the utility sector. Asset management in the utility sector is how to manage all the components of a network, to improve efficiency, cut costs and save time (McMahon, 2016).

The first major industry to utilize GIS was the water industry, but over the last few decades all of the major industries, including electric, have started to utilize the powers of GIS to manage network assets (Lutchman, 2006). Like with many utility infrastructures, the cost of maintaining an electric network is significant, therefore any way of reducing these costs should be sought (Schneider et al., 2005). There are a few different ways that GIS can help organizations save money through asset management. GIS can help to create maintenance strategies (Schneider et al., 2005). It can also allow a user to run simulations on a network. For example, with the implementation of a Geometric Network from Esri, one can run an analysis to determine what transformers are most susceptible to failure due to a higher load weight. Knowing information such as that can help an electric department work out how to solve the issue; by increasing the size of the transformer or distributing the load to nearby underutilized transformers (Murad-al-Shaikh, 2018).

GIS is not the only way of managing utility assets, there are other products that have been used for a while. For example, Computer Aided Design or CAD is often used. The City of Aspen used to store all of its water utility assets in CAD. CAD data is often very accurate, but where it differs from GIS is that it does not have a geographical location tied to it (Peachavanish. et al, 2005).

2.2 GIS Utility Data Collection

As with anything utilizing GIS, the most important part is having good data; an organization's database is only as good as the information in it (Jones & Henry, 2018). Therefore, collecting accurate and correct data is an important factor for building a utility network in a GIS framework. There are many ways of collecting data from high tech surveying to using a smartphone; this section will discuss the latter.

Using a smartphone to collect data comes with its challenges. When collecting spatial data, there are a few things that one should look for; these are often referred to as the “famous five” (Pundt, 2002). They are “lineage, positional accuracy, attribute accuracy, logical consistency, and completeness.” (Pundt, 2002). The question is what applications best allows the user to meet their requirements in these five categories. This project looked at only Esri data collection applications and in particular, Collector and Survey123.

Collector is a map-based application from Esri that allows the user to collect data for any vector-based feature class (Esri, n.d.) According to Sheehan (2014), Collector is popular with both GIS and non-GIS users due to its ease of use and customization options. Although the application is easy for non-GIS users to use, the initial setup requires GIS skills, due to its use of schemas for different feature classes. This is a drawback to Collector (Meador & Horn, 2017).

An application that is also from Esri that allows for non-GIS users to set up and configure is Survey123. Survey123 is a form-based application. Therefore rather than looking like a map when collecting data, it looks similar to a standard survey. One of the best parts is that this allows the survey to have drop down menus for all the fields, reducing possible attribution errors when collecting data (Esri, n.d.)

An important thing to take into account is accuracy, especially when using mobile devices for data collection. Depending on how accurate the positional accuracy is desired to be, it might be necessary to pair an external GPS to a mobile device (Wing, Eklund & Kellogg, 2005).

2.3 Augmented Reality for Utilities

Augmented Reality or AR is when virtual elements are imposed on a real-world scene; it is often confused with Virtual Reality or VR, which is when technology imposes a different world to the user, for example in movies and video games (Isberto, 2018). AR has been around since the 1960s but has grown in use over the last decade. There are many different ways that the powers of AR have been utilized including sports broadcasting, interior designers, aids for surgery, and personal entertainment (Marr, 2018).

Figure 2-1: Different applications of AR, left surgery, right interior design.

Depending on the application and reason for using AR there are different parameters that need to be met. For example, accuracy can play a huge rule in how well an AR product can be used. For surgery the highest accuracy is crucial, as millimeters can make a huge difference to the success of an operation (Murthi, 2018). At the other end of the spectrum AR applications that are created for pleasure or games, like Pokémon GO do not need to be as precise. That being said, a phone’s GPS still does need to be capable of placing the virtual object within a reasonable distance of its intended location (Dormehl, 2018). There are many different phones, and therefore their GPS’s have different levels of accuracy. Dormehl (2018) stated that “One problem with AR location experiences is the low accuracy of phone GPS and compasses, which makes it difficult to ensure that things line up.” Even though there is debate on as to how accurate AR and phones can really be, there are still many different AR mobile applications that are available.

One area that this project focused on was how utilities, in particular electric, could utilize AR technology. Chebra (2018) stated that “bringing AR to utility field personnel can provide an excellent way of presenting data when and where it’s most needed”. Later in the article Chebra talks about why AR could be useful. One example discussed is how AR could help a lineman respond to a power outage. The lineman could use his phone, point it at the damaged equipment and quickly access a list of attributes pertaining to the broken component. This would allow him to quickly understand what parts he would need to collect, or order, for a replacement (Chebra, 2018).

The utility industry has been suffering from a rapidly retiring workforce. The workers who are replacing the retirees are younger and want to use the latest technology (Stone, 2016). AR is one such technology that can help bring this change to the utility industry. At the base of an AR model for viewing utilities, there needs to be precise and accurate data. Although there are a few ways of storing this data, GIS is fast becoming the standard. The Toms River Municipal Utilities Authority (TRMUA) in New Jersey has

Figure 2-2: Utilizing AR to view underground utilities.

been at the forefront of utilizing AR to view their underground assets. TRMUA pairs an accurate GIS utility model with a holographic headset to allow their field crews to know exactly what is going on underground (Meehan, 2017). An example of what they have created can be seen in Figure 2-2.

In addition to organizations creating their own AR applications, like TRMUA. There are also companies that provide AR technology through a custom mobile based application. Companies such as ARGIS Solutions and Augview offer custom mobile applications to allow for GIS layers to be viewed through just a phone's camera. Both companies have a minimum requirement on what will work for their applications. For example, Augview, who specializes in underground utilities for their AR application, states that the minimum operating system of Android 4.0 is needed and that the phone/tablet must have a magnetometer, rear facing camera, GPS, gyroscope and accelerometer (Augview, 2018). All of the products from these companies have a cost associated with them. However, there are also some free AR applications that claim to be able to accurately display GIS layers. One such product is AuGeo. AuGeo is a free application from Esri that states that any point feature class on ArcGIS Online can be viewed through this application. It is not specifically for underground utility modeling, but theoretically it should work. This project discovered some of the drawbacks to AuGeo, with the biggest issue being that the application could not accurately locate locations.

2.4 Summary

This chapter discussed background research and relevant literature was reviewed. It started by stating the history of asset management and when utilities also started to utilize GIS for asset management. Examples of the benefits of utilizing GIS for electric asset management were also discussed. The next section discussed using GIS to collect data in the field. In particular, two Esri applications were discussed: Collector and Survey123. The final section talked about how AR and utilities can be combined. An example of a utility organization employing AR technology in New Jersey was examined.

Chapter 3 – Systems Analysis and Design

Chapter three discusses how the City of Aspen can be ready to migrate its electric utility assets into the Esri Utility Network. The existing problem will be discussed and then the client's requirements will be explained. The initial project plan on how to reach those requirements and goals will be described.

3.1 Problem Statement

The City of Aspen has an underground electric utility network that has historically only been understood by a handful of employees. Over the last few years, the City of Aspen has pushed to migrate its utility assets into a GIS format. This includes the electric network. To start with, the location of transformers and primary lines were located and recorded. A few years later there was an effort to collect additional information, such as service points, secondary line locations, and additional attributes about the transformers. During this time the water department had also successfully moved its assets into a geodatabase. In 2019, the City of Aspen wants to move its utility assets into Esri's new Utility Network (UN). The UN is an updated model for managing and performing analysis on utility networks; it is the replacement for the geometric network.

Before the electric network was ready for this migration, a few things had to be done to the existing network; more data needed to be collected from the field, and the integrity of the previously collected data needed to be reviewed to ensure it was accurate.

The City of Aspen's electric department also does not have any easy way to view their assets in the field. Therefore, the creation of an Augmented Reality (AR) mobile application was desired.

3.2 Requirements Analysis

To meet the objectives that the City of Aspen had desired there were a few requirements that needed to be met. The requirements were split into three different sections: data collection, data integrity and viewing the data. The requirements are explained below and listed in Table 1.

For the data collection portion of the project, the client wanted a mobile application that could be used to collect additional and new attributes for the electric network.
The second portion of the project was improving the existing data's integrity. The client had an existing geodatabase that was from the Esri electric solutions team and was targeted for electric asset management. The requirements that the client had for its geodatabase was for the existing schema not to be altered, but for the data to be cleaned. They wanted the network to be correctly connected with the correct topology rules in place.

The final portion of the project was making an application that would allow the electric crew to view their assets in the field. The application would be an augmented reality (AR) application that the electric department could use with the camera built into their phones or tablets.

Table 1. Deliverables and requirements for project.

Deliverables	Requirements
Mobile Data Collection Application	- Ability to function offline - Ability to edit existing feature classes - Ability to add new features to feature classes - Use domains and subtypes whenever applicable - Ability to sync to ArcGIS Online features
Topologically Corrected Geodatabase	- To use existing schema - Geodatabase to be free of topology errors - Line work to be adjusted for a cleaner look
Mobile Augmented Reality Application	- Mobile application to utilize the device's camera for augmented reality - Ability to use the same features classes as the data collection applications - Ability to function offline

3.3 System Design

There were three major components to this project: future field data collection, improving existing data integrity, and viewing the data in the field. The data collection portion used mobile surveys using the Esri Survey123 application. Each feature class that had existing data had its own unique survey. The existing data had many connectivity issues that needed to be resolved for a successful future migration into the UN. After the existing data was cleaned up, it could then be used in an application that allowed the electric department to view its assets in an AR mobile platform. A diagram of the system design can be seen in Figure 3-1.

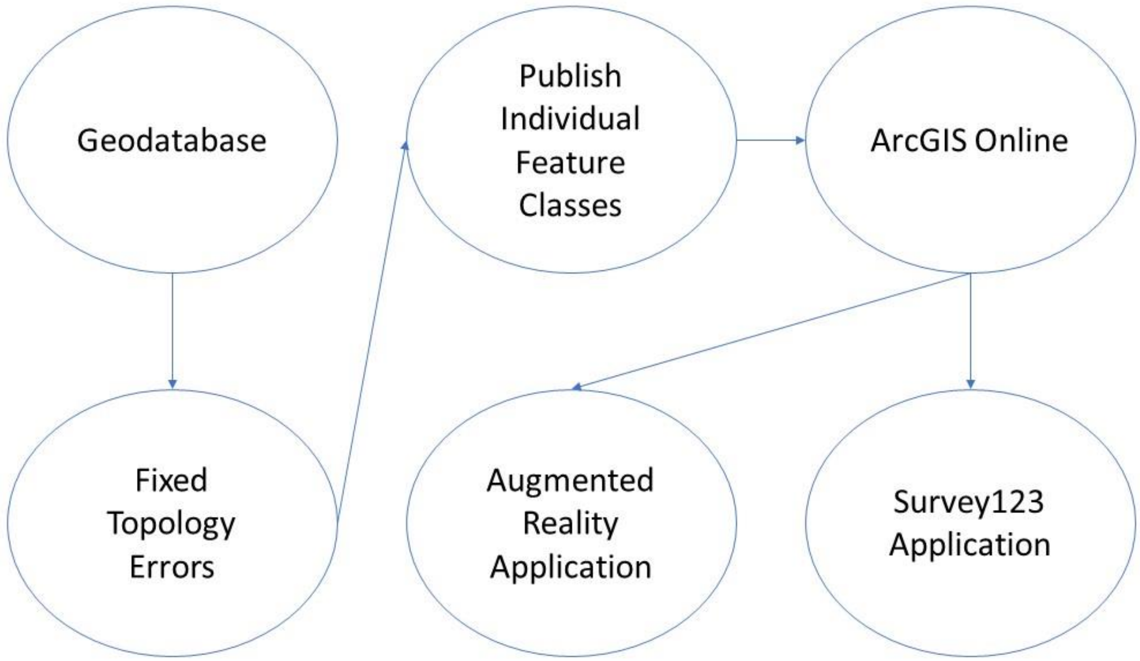

Figure 3-1: A diagram of the system design

3.4 Project Plan

At the start of the project the aim was to get the mobile collection application built first. This would have allowed the electric department to have the ability to make edits in the summer when most changes are being made to the network. The initial idea was to use the Collector application from Esri. What was discovered was that Collector is good for collecting new data, but editing existing data is not quite as easy a task. Therefore, we decided to switch to Survey123. Survey123 is also a product from Esri; it's a form-based application, as opposed to Collector, which is map-based. Survey123 worked well for this application as it allowed for both the creation of new points but also the editing of existing features. Since each field had its own area on the survey, domains could be created to make it easier for field crews to input data with little typing and margin for error.

In reality, the ambitious goal of having the mobile collection applications done before summer was not realistic, and instead they were just added as a final deliverable for the end of the project. The final deliverable for data collection was a Survey123 application for each feature class in the electric geodatabase that had existing data loaded into it. Each of those surveys had drop down domain menus whenever applicable and had the option to add photos if desired.

The second portion of the project was cleaning up the existing data to ensure that it was all topologically correct. Initially, Data Reviewer was going to be used to determine where the errors were. Esri has a batch rule set for their electric geodatabase; this batch ruleset was run. Most of the rules included attribution errors. Fixing these errors would have required a lot of additional field work and data collection. Since this wasn't an option, it was decided to focus on the topology errors of the dataset. In addition to fixing the topology errors, the visual appearance of the electric lines were edited to make for a cleaner and easier to read network. The geographical locations for the lines were not accurate, so changing the lines to not overlap made for a good visual improvement. Figure 3-2 shows a before and after of the adjusted line work.

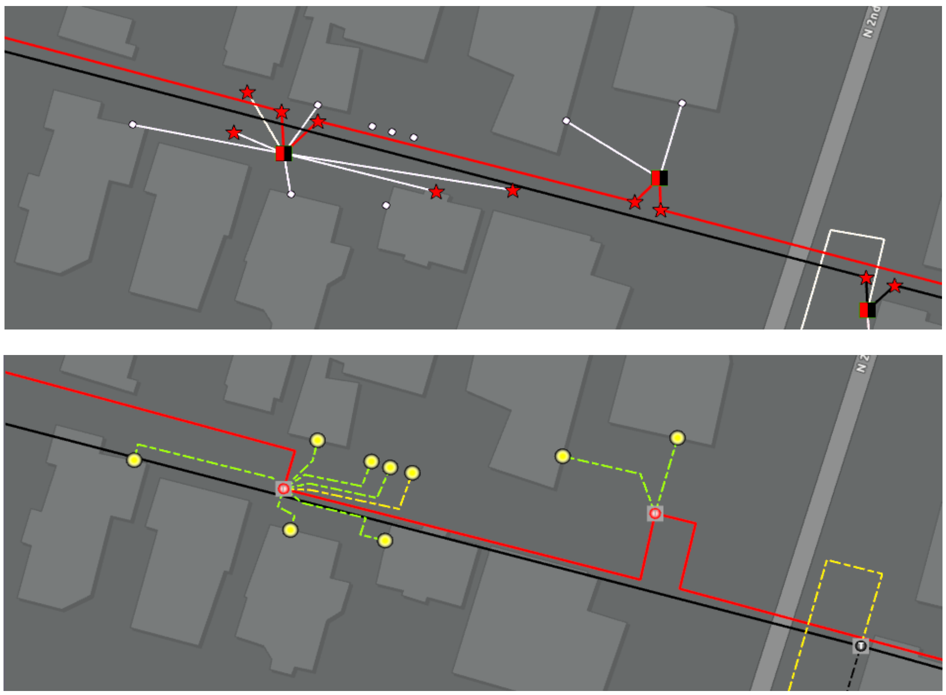

Figure 3-2: Before (top) and after (bottom) line work had been completed

It was hard to gauge how long this portion of the project would take without diving into the data. After doing a small pilot on a small area of the dataset, it was determined that this part of the project may take a good portion of time, and that enough resources should be set aside for it. This portion of the project did indeed take a lot of time to make the geodatabase topologically correct and to improve the aesthetics of the linework.

The third portion of the project was not a direct requirement from the client, but I thought it made sense and added it to the overall project. The deliverable for this portion was a mobile application that allowed the electric crew to view their assets in an Augmented Reality (AR) view. This portion of the project was added later and was therefore not as important of a requirement. A smaller time allotment was allocated for the AR application creation. This part of the project definitely has room for future expansion and refinement, but I did what was possible with the time constraints that I had.

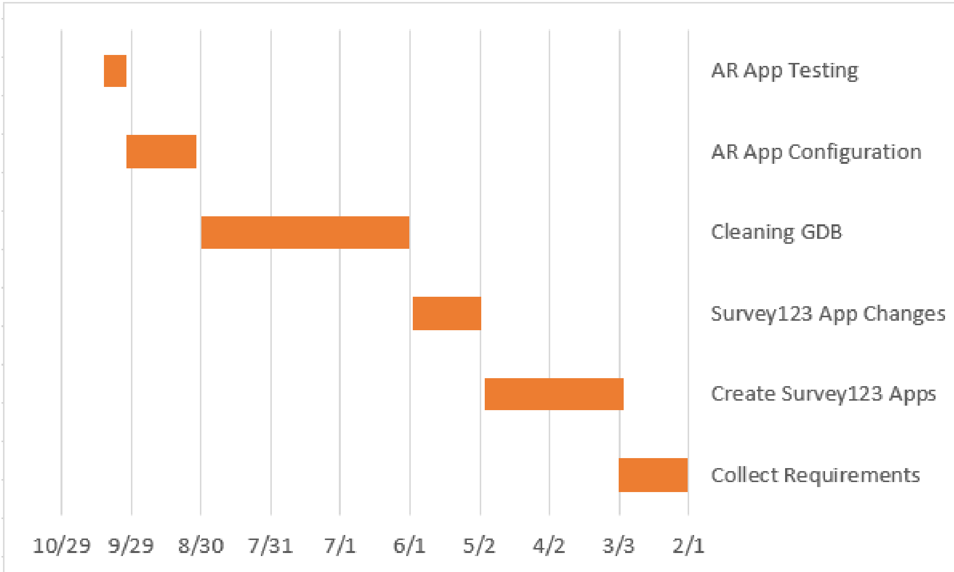

Figure 3-3: Gantt Chart of original timeline

3.5 Summary

This chapter started by discussing the client's problem and why it needed to be solved. Following the problem statement, the client's goals and requirements for the project were discussed. The chapter went on to discuss the three sections of the project and how they were originally planned versus how they ended up.

Chapter 4 – Database Design

This chapter will discuss the conceptual and logical data model for this project. It will then go on to talk about the data: the data sources, how the data was collected and what had to be done to the data to allow it to be edited for this project.

4.1 Conceptual Data Model

The conceptual data model lays out how the database should be set up and what the separate components are. To understand the conceptual model, it is first important to understand how electric distribution networks work, and in particular, how Aspen's electric distribution network is set up.

Every electric network has a source, which is where the electricity enters the network. In the case of Aspen, it comes from a third party electric supplier, the Holy Cross Energy Company. It enters the city's network at the switching facilities. The switching facilities then feed the power into the primary lines. Along the primary lines there are three possible features: open points, vaults, or transformers. An open point allows the power to be isolated in a certain area. A vault is a way of accessing the underground assets; they are mainly used for maintenance. A transformer distributes power from a primary line to a smaller secondary line. A secondary line in the case of Aspen, supplies power to either a service point or a pedestal. A service point is the point at which the electricity reaches a customer. A pedestal is similar to a service point, although it can service multiple customers. This model is depicted in Figure 4-1.

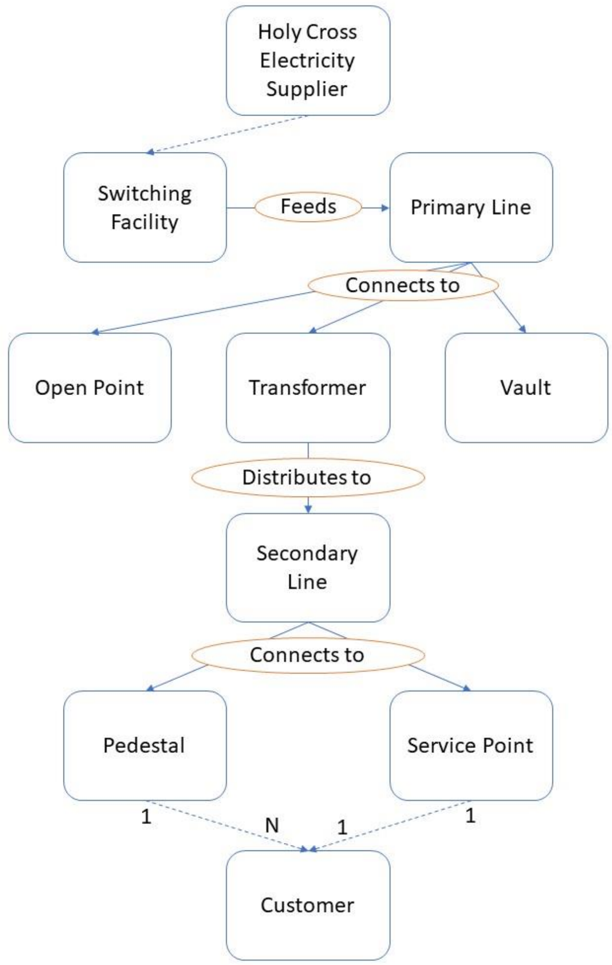

Figure 4-1: The conceptual data model for the City of Aspen's electric distribution network.

In addition to designing the model to go from the power source to the customer, the client also wanted to model how the electricity flows through the switching facilities themselves. The City of Aspen has two different types of switching facilities: PMH and Vista. Depending on which type of switching facility is being used, there will be a combination of fuses, circuit breakers and switches inside of it. An example of how a switch facility is depicted in GIS is shown in Figure 4-2. In addition to having a conceptual data model for the whole network, it was also important to have one for how the inside of a switching facility is modeled. Figure 4-3 shows a diagram of the conceptual model for the inside of a switching facility.

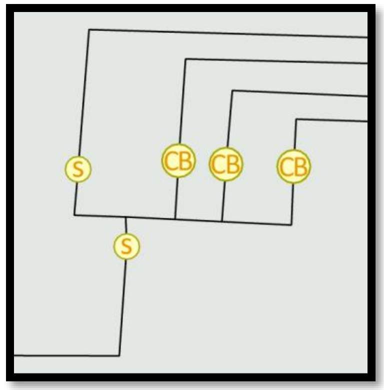

Figure 4-2: How a switching facility is depicted in GIS. The black lines are primary lines.

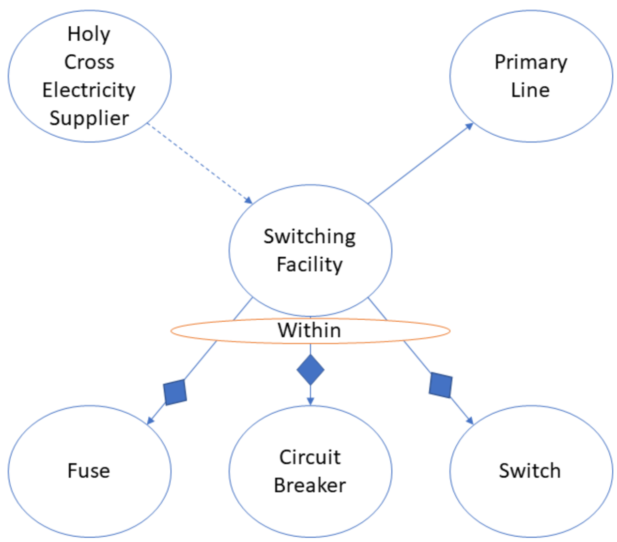

Figure 4-3: The conceptual model for the inside of a switching facility.

4.2 Logical Data Model

The City of Aspen had a geodatabase implemented for its existing electric datasets. This geodatabase was created by the Esri ArcGIS electric solutions team. The geodatabase was created to fill a wide range of electric distribution needs, therefore many of the features were not relevant to Aspen's small underground electric network. Although there were many feature classes that were not being utilized, the client wanted to keep them in the geodatabase in case they wanted to populate those feature classes in the future.

When the City of Aspen first implemented its geodatabase, some custom configuration was performed to further meet its desired needs. The major changes that had been made were to edit the domains and subtypes to match the assets they wanted to record. The default geodatabase came with a lot of domain options that were often not necessary or relevant for the City of Aspen's electric network. Therefore, any domain options that would never be utilized were deleted, and ones that were not in the original lists were added. Since the client already had a working geodatabase that was built by electric distribution networks experts, it was decided that the existing geodatabase would still be used and that a new one did not need to be created for this project

In the geodatabase there was a total of 33 different feature classes with 43 relationship classes although only 13 of the feature classes were being utilized. The feature classes that were used can be seen in Figure 4-4.

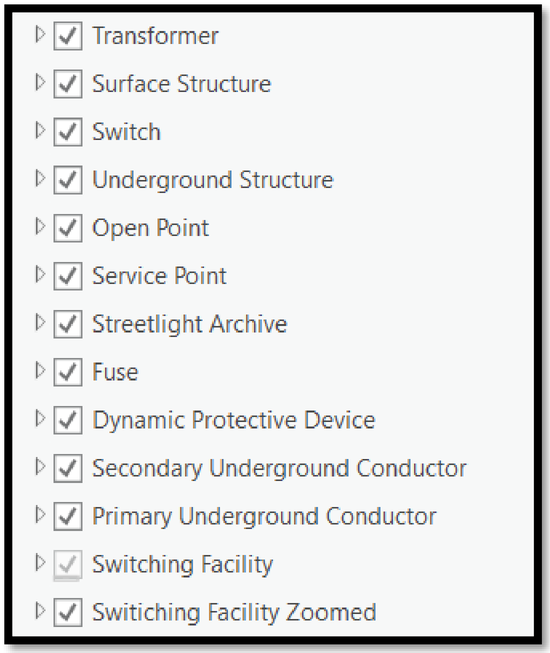

Figure 4-4: List of the 13 feature classes that were utilized for the project.

All of these feature classes had numerous fields. As this geodatabase was aimed at electric networks in general, there were many fields that did not currently pertain to the City of Aspen's network. Therefore, the fields of the 13 feature classes were reviewed by the electric department staff and they decided which fields they wanted to use. The fields that were not going to be used were hidden. They were not deleted because the electric department wanted to have the option to unhide a field and use it later. For example, they currently do not have a naming convention in place for their transformers or a transformer ID. This is something that they want to do at some point in the future but because it was not imminent it made more sense to hide that field. A detailed look at each of the fields of the 13 utilized feature classes fields can be seen in Appendix A.

4.3 Data Sources and Scrubbing

All the data for this project came from the client, the City of Aspen. The data had been collected over the last few years by numerous staff in the electric and engineering departments in the city. Due to the nature of an underground electric network, often not the exact location of a buried line is not known. Although some of the feature classes are geographically correct, such as the transformer and vault locations, the primary and secondary lines are not geographically correct, although the general location and direction is known; for example, it is known that a primary line is in the Hopkins alley and that it is connected to transformers A and B. The exact locations of the service points and pedestals were not always known. However, the service points often had an associated address and had been placed on the matching address building footprint.

No metadata was provided. Metadata was completed for the necessary fields in the electric distribution geodatabase. Since there were many unused fields in the geodatabase, it was only necessary to complete the metadata for feature classes that had data or were planning on being used in the future by the electric department.

4.4 Summary

This chapter started off by talking about the conceptual data model. Following the conceptual data model, the logical data model was described. Then information about the data was discussed; where it came from and the data scrubbing process.

Chapter 5 – Implementation

This chapter will go through a detailed look at how each portion of the project was accomplished. It will start by going through the creation of the data collection mobile applications it will be followed by the cleanup process for improving the integrity of the geodatabase. The final section will depict how the augmented reality (AR) application was created and used.

5.1 Initial Preparation

The first thing that had to be accomplished for this project was getting the data that was provided from the client into a useable format. The provided geodatabase was extracted and opened into an ArcGIS Pro project; in ArcGIS Pro a basic map (Figure 5-1) was created using similar symbology to the currently existing online electric web map for the City of Aspen.

The next task was to publish each individual layer to ArcGIS Online (AGOL). This was where the first problem was encountered with the data. The provided data was in a geodatabase that was created by the Esri electric solutions team with the specific goal of managing electric utility assets. This geodatabase has a Geometric Network built into it. Many parts of a Geometric Network are not compatible with ArcGIS Pro; the data can still be viewed but aspects of the functionality, such as editing, cannot be done and would have to be done in ArcMap. In addition to not being able to edit, feature layers cannot be published to AGOL from ArcGIS Pro if they are part of a Geometric Network. To get around this problem, a new geodatabase was created, and the needed layers were copied into it. This new geodatabase didn't have the Geometric Network created, and therefore it was able to publish the necessary feature layers to AGOL. There was a total of 13 feature layers published to AGOL (Figure 5-2). Each layer that was published was also configured to allow for attachments. Enabling attachments was done to allow the electric crew to take and store pictures; for example, they could take a picture of an information panel inside of a transformer for future reference.

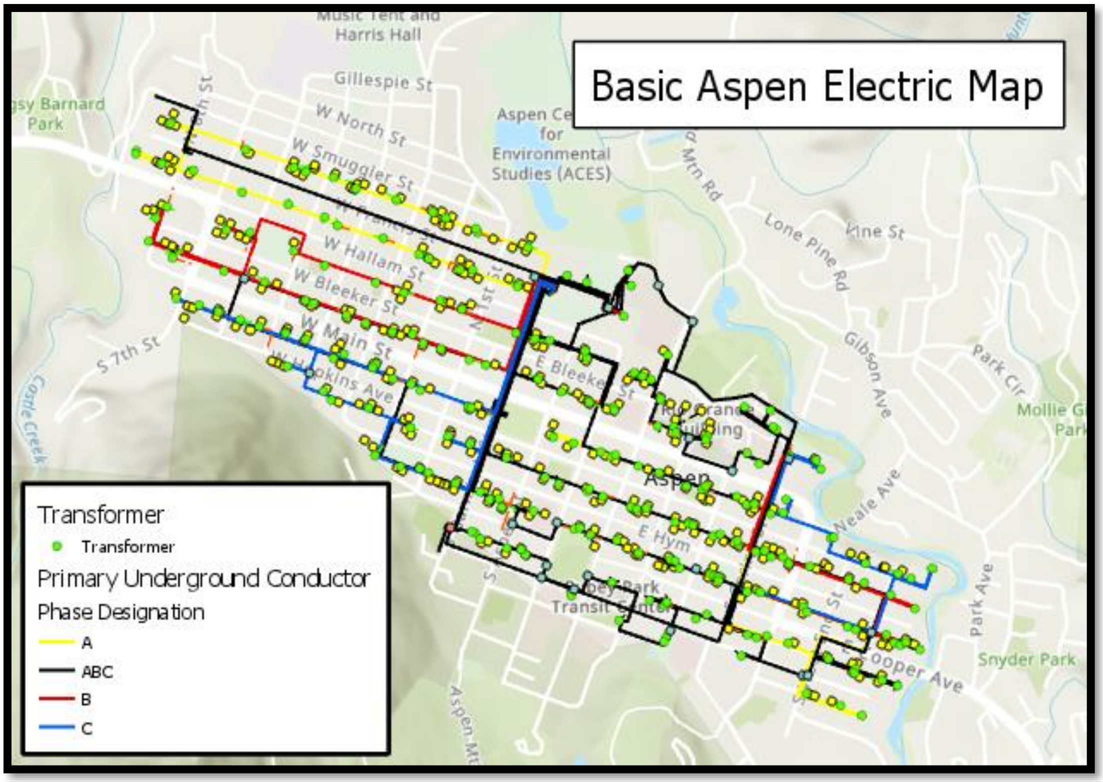

Figure 5-1: The basic map that was created for editing.

Dynamic Protective Device	Jul 14, 2018	hamish_henderson@rec	5
~~Electric_Distribution~~	[illegible]	~~CityofAspenGIS~~	[illegible]
Fuse	Jul 9, 2018	hamish_henderson@rec	2
Fuse_Current_Limiting	Jul 14, 2018	hamish_henderson@rec	1
Open Point	Jul 14, 2018	hamish_henderson@rec	5
Pedestal	Jul 14, 2018	hamish_henderson@rec	1
Primary Underground Conductor	Jul 14, 2018	hamish_henderson@rec	9
Secondary Underground Conductor	Jul 14, 2018	hamish_henderson@rec	3
Service Point	Aug 21, 2018	hamish_henderson@rec	5
Splice_Vault	Jul 14, 2018	hamish_henderson@rec	1
StreetlightArchive	Jul 9, 2018	hamish_henderson@rec	1
Switch_UG_Load_Break	Jul 14, 2018	hamish_henderson@rec	1
Switching_Facility	Jul 14, 2018	hamish_henderson@rec	1
Transformers	Jun 4, 2018	hamish_henderson@rec	5

Figure 5-2: Feature classes published to AGOL.

5.2 Creating Survey123 Applications

The electric department wanted to have a way of collecting data from either their phones or tablets when they were in the field. In addition to collecting new data, they also wanted to be able to edit the data they already had. Survey123 was chosen as the application to use. Survey123 is a form-based application by Esri that allows users to use an existing feature class to create a survey with matching fields. The other application that was considered was using the Collector application, Collector is good for collecting new data but not as user friendly for updating existing data. For this reason, it was decided that Survey123 was a better option for the requirements of this project.

There are two different ways that a Survey123 application can be created; one way is using the Survey123 website and the other option is using Survey123 Connect. Survey123 Connect is an application that is downloaded onto a desktop, and it allows for the most custom configuration abilities. Survey123 Connect also allows the user to create surveys using an existing feature class. This is not an option on the Survey123 website. Using an existing feature class allows the user to edit the existing data. It also imports all the existing fields into each survey's associated Excel spreadsheet.

This spreadsheet can configure which fields are to be displayed, add domains, set defaults, and enable attachments. Initially the surveys were created with every field that was originally in the electric distribution geodatabase. It was known that some fields would need to be deleted, as not all the fields are pertinent to City of Aspen's electric network.

The Survey123 application has the ability to have and utilize domains. However, when the survey is created from the original feature class, it does not bring the domains over with it. Therefore, they must be added manually. The first thing that needed to be done was to create a spreadsheet of all the domains in the electric distribution geodatabase. This was done to save time by not having to look up what each domain included for every field. A basic Python script was created that wrote all the domains from the electric distribution geodatabase to an Excel spreadsheet. This script can be seen in the Appendix B. ArcGIS Pro was used to determine which domains were associated with each field or subtype for each feature class (Figure 5-3). The domains were entered into the "choices" tab in the Excel spreadsheet. Each domain has a "name," "label" and "list_name" column. The "list_name" is entered into the associated field (Figure 5-4). The survey field will have its associated domain linked via the "list_name". This technique was used on all the surveys.

Domain Name	Description	Field Type	Domain Type	Split Policy	Merge Policy
Over Current Prot Dev Nominal Voltage		Long	Coded Value Domain	Duplicate	Default
Overhead Primary Insulation Type		Text	Coded Value Domain	Duplicate	Default
Overhead Secondary Insulation Type		Text	Coded Value Domain	Duplicate	Default
Phase Designation		Long	Coded Value Domain	Duplicate	Default
Pole Class		Text	Coded Value Domain	Duplicate	Default
Pole Foundation Type		Text	Coded Value Domain	Duplicate	Default
Pole Height		Text	Coded Value Domain	Duplicate	Default
Pole Material - H-Frame		Text	Coded Value Domain	Duplicate	Default
Pole Material - Non-Wood		Text	Coded Value Domain	Duplicate	Default
Pole Material - Tower		Text	Coded Value Domain	Duplicate	Default
Pole Material - Wood		Text	Coded Value Domain	Duplicate	Default
Pole Style		Text	Coded Value Domain	Duplicate	Default
Pole Treatment Type - Non-Wood		Text	Coded Value Domain	Duplicate	Default
Pole Treatment Type - Wood		Text	Coded Value Domain	Duplicate	Default
Pole Use Type		Text	Coded Value Domain	Duplicate	Default
Power Transformer Cooling Type		Text	Coded Value Domain	Duplicate	Default
Power Transformer Low Side Voltage		Long	Coded Value Domain	Duplicate	Default
Power Transformer Nominal Voltage		Long	Coded Value Domain	Duplicate	Default
Present Status		Long	Coded Value Domain	Duplicate	Default
Primary Insulation Voltage		Text	Coded Value Domain	Duplicate	Default
Primary Meter Type		Text	Coded Value Domain	Duplicate	Default
Primary Nominal Voltage		Long	Coded Value Domain	Duplicate	Default
Rated kVA - Single Phase		Long	Coded Value Domain	Default	Default
Rated kVA - Three Phase		Long	Coded Value Domain	Default	Default
Recloser Bank Mounting Type		Text	Coded Value Domain	Duplicate	Default
Recloser Electronic Control Model		Text	Coded Value Domain	Duplicate	Default

Code	Description
4	A
6	AB
5	AC
2	B
3	BC
1	C
7	ABC

Figure 5-3: The process for viewing what a domain contains in ArcGIS Pro

1	list_name	name	label	imag
2				
3				
4	EnabledDomain	0	False	
5	EnabledDomain	1	True	
6				
7	Electric Device Operating Voltage Single	14	14.4 kV Grounded Wye	
8	Electric Device Operating Voltage Single	24	24.9 kV Grounded Wye	
9				
10	Construction_Status	0	Proposed	
11	Construction_Status	5	Existing	
12	Construction_Status	10	Waiting For Staking	
13	Construction_Status	15	Staked	
14	Construction_Status	20	Proposed Retired	
15	Construction_Status	25	Proposed Abandoned	
16	Construction_Status	30	Retired	
17	Construction_Status	35	Abandoned	
18				
19	TransformerBankHighSideProtection	D	Delta	
20	TransformerBankHighSideProtection	OD	Open Delta	
21	TransformerBankHighSideProtection	OY	Open Wye	
22	TransformerBankHighSideProtection	LG	Single Phase Line - Ground	
23	TransformerBankHighSideProtection	LL	Single Phase Line - Line	
24	TransformerBankHighSideProtection	Y	Wye	
25				
26	Location Type	DLV	Delivery Point	
27	Location Type	GEN	Generator	
28	Location Type	PRI	Primary Meter	
29	Location Type	SVC	Service Point	
30	Location Type	NONE	None	

Figure 5-4: Example of the formatting for domains in Survey123 Connect.

After the domains were added into the Excel spreadsheet, the order of the fields was altered to resemble fields that were already being used by the electric department. In each survey's Excel spreadsheet, there was the ability to enter default values; these were added where applicable.

The next step was to publish the surveys. These surveys were published through Survey123 Connect and then shared with the City of Aspen's ArcGIS Online electric group. The surveys were then downloaded to the electric department's mobile phones and reviewed by the staff to see what was missing and which fields were not needed. The list of fields to be removed is in Appendix C.

Once feedback was received from the electric department, the surveys were edited to delete all the unnecessary fields. Another requirement that had been missed in the first draft was for the ability of the surveys to store photographs. The electric department wanted this requirement, so they could take pictures of all the features in the field, such as a transformer's information plate, Figure 5-5. To have images, the original features classes on AGOL had to be configured to enable attachments, which was done when the data was published to AGOL. In Survey123 Connect there is also an enable attachments options. In addition to enabling attachments in AGOL and Survey123 Connect, there also has to be a field in the corresponding Excel file called "attachments." Once these three components have been added in, the survey is able to capture and store photographs, and videos if desired.

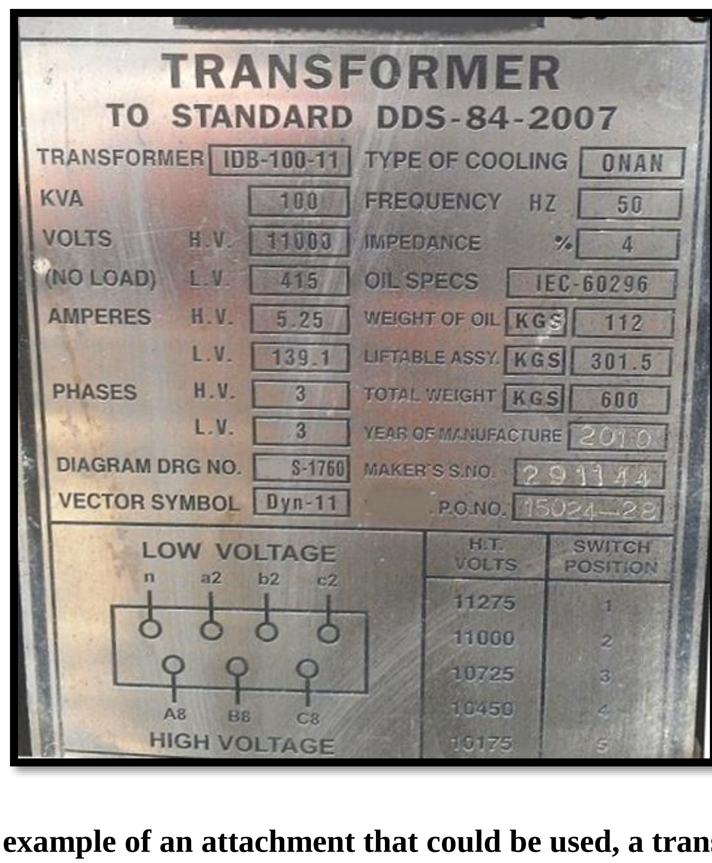

Figure 5-5: An example of an attachment that could be used, a transformer information plate.

The last thing that needed to be done before the final surveys could be published was to create thumbnails and fill in the relevant information in the description and online feature classes. Since there were multiple surveys, the thumbnails were made to be simple, just having the City of Aspen's logo and some text stating what survey it was, Figure 5-6 shows these thumbnails. The thumbnails were created in Adobe Photoshop and were all the standard AGOL thumbnail size of 600 x 400 pixels.

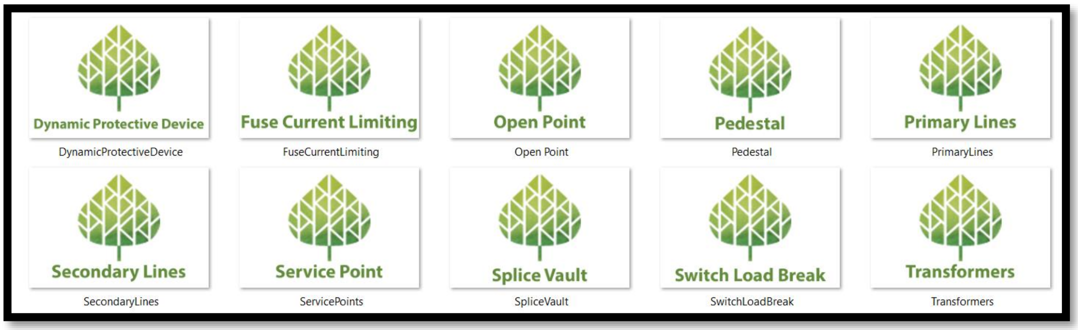

Figure 5-6: Thumbnails created for Survey123 forms

5.3 Improving Geodatabase Integrity

One of the biggest tasks for this project was cleaning up the data that had previously been collected. The existing data looked like it was correctly connected when it was viewed from a zoomed out view. However, when the data was enlarged, it was clear that many of the connections were not correct and many were not even connected at all (see Figure 5-7). In addition to bad connections there were also many problems with the line work. The primary lines had been broken up into numerous little segments, instead of one large segment from point to point.

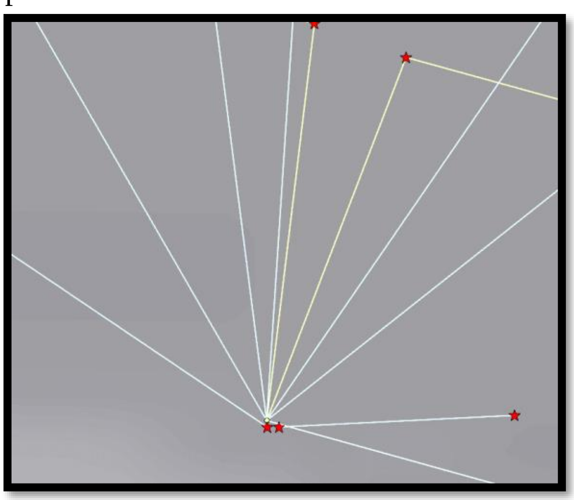

Figure 5-7: Screenshot of old data showing topology errors (red stars).

The first task was to fix the segmentation in the line work. The goal for this portion was to have one segment between each point feature; for example, if there were two transformers (point feature class) in a block, they would have one continuous line between them. The process for fixing this line work was to use the merge tool. All of the segments between each point would be selected, then the merge tool would be run to combine them into one.

After all the underground primary lines had been fixed to the minimum number of segments, the next task was to clean up the actual line work. The exact geographical positions of the lines were not known as they are all underground. However, the spatial location of the transformers were all known. Therefore, the rough position of the primary lines is known, the existing lines had overlaps with other lines and had inconsistent angles going to the transformers. The electric department wanted the lines to not be overlapping whenever possible; instead they should run parallel to each other. They also wanted to just use 90-degree angles at junctions and overall just wanted a cleaner and easier-to-follow layout. To adjust the primary underground lines required editing the vertices of the lines. Each segment was made with as few angles as possible. Figure 5-8 shows the same area both before and after the primary underground lines had been edited.

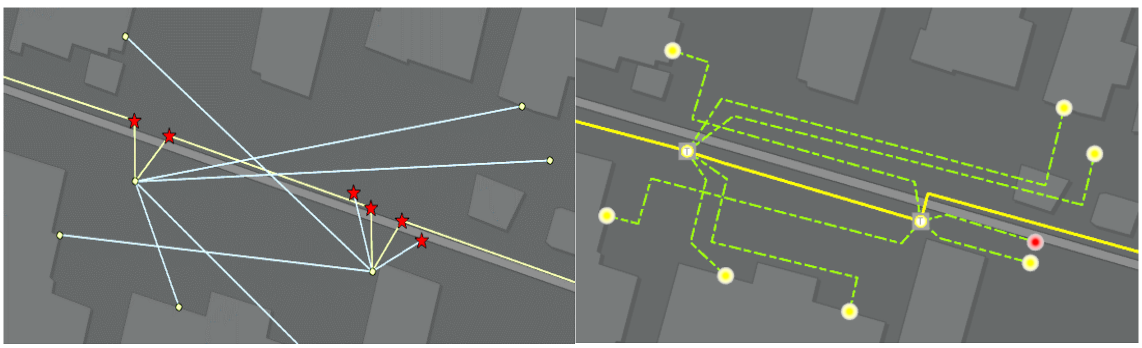

Figure 5-8: The primary lines before (left, pale yellow line) and after (right, yellow solid line)

After the primary lines were adjusted and fixed, the next task was to fix the service points. In a Geometric Network there are "net junctions" that are automatically created when the feature classes are populated. A net junction is essentially telling the user where there are topology connectivity errors that violate a rule that was set up when the Geometric Network was created. One of these errors is that there should be a point at the end of each secondary line. In the case of the City of Aspen, these points should be service points or in a couple rare cases, pedestals. There were 619 secondary lines in the network, but only 343 service points in the feature class. Therefore, there were 276 service points that needed to be located and added. Many of these service points could be calculated by looking at the address attributes for the secondary lines. The service points that were known were placed on the respected building footprint. Although, there were still numerous service points for which the exact location could not be determined. These service points were still added to the network just with an address location of "unknown." At the same time as adding the new service points, the secondary underground lines were also adjusted to not be overlapping, crossing through other building footprints, and generally adjusted to be more user friendly. Figure 5-9 shows a before and after of the same area with secondary lines and service points added.

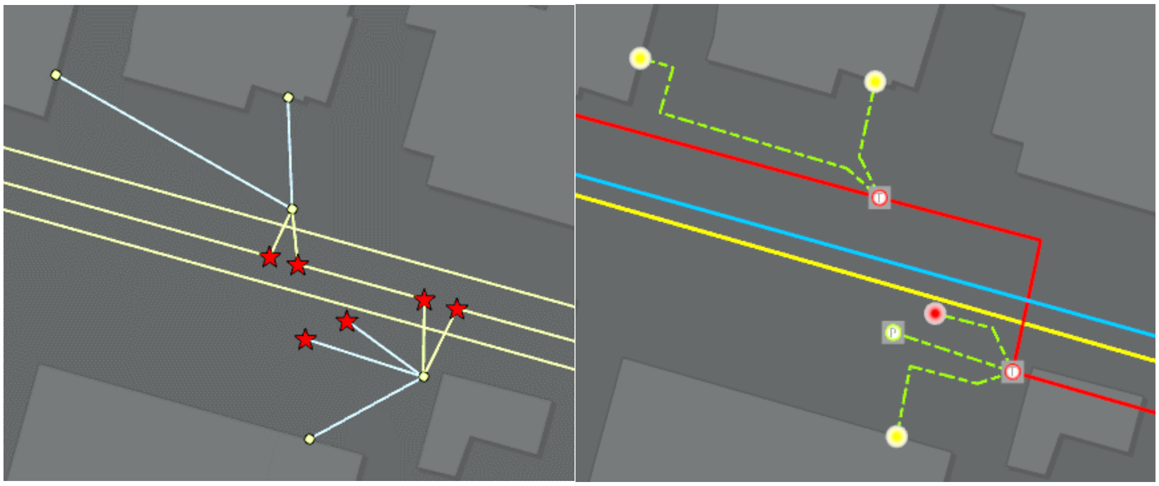

Figure 5-9: Before (left) and after (right) of service points (yellow/red circles) and secondary underground lines (dashed green) edited

After the service points had all been added and the primary lines merged, the number of net junctions was only at 7. These remaining net junctions were special cases that were spread throughout the network, but were mostly based around where electricity was coming into the network from an outside source. After talking with the electric department, it was agreed that these few remaining points could be exempt, and that the electric department would decide what they wanted to do with them after the project was completed.

Now that the network connections had all been sorted and the line work had been cleaned up, the next step was to migrate the data from the ArcGIS Pro project geodatabase back into the old schema. The easiest way to do this was to export the schema as an XML document from the original geodatabase. After the schema had been exported, ArcMap was used to load the new edited data back into the schema with the Geometric Network.

The electric department had an online web map that it uses to view the electric network when staff are in the office. The final stage of the data integrity portion of the project was to create a web map of the electric network. The first step was to make basic symbology symbols. The symbology was created by reviewing industry standards and referencing the existing web map that the electric department was using. All the symbology was created and applied in ArcGIS Pro and then each layer was republished back to AGOL. Once the layers had all been republished a web map was created. Scale limits were set to match the original web map, and the popups were configured so that only the fields in the Survey123 apps were shown. Figure 5-10 is a screenshot of the web map.

Figure 5-10: Screenshot of the web map

5.4 AuGeo Application

AuGeo is an Augmented Reality (AR) application that allows the user to use feature classes that are hosted in AGOL, and it then projects these feature classes into the "real world" through the lens on a smart device's camera. The idea was to create an application that would allow the electric department to use its phones' cameras to view the underground electric assets. This was a deliverable that the client had not explicitly requested, but thought it would be an interesting idea. Therefore, it was allotted the least amount of time, which leaves room for future expansion.

The initial set up of AuGeo was fairly straightforward. After the applications had been downloaded onto a mobile device, the application needed to be configured for the desired feature service in AGOL to allow it to be viewed in AuGeo. To configure the feature service, the tags needed to be changed to include the tag "AuGeo".

After the tag had been added, the pop up needed to be configured. The pop up is configured in the visualization tab. In AuGeo only the title is used for the pop up. This limits the size of what can be placed as the pop up. For the electric services the most relevant attributes were chosen. For example, the attributes for the transformers service were the "Rated kVA" and the "Percent Impedance,". After the pop up had been configured all of the AGOL setup was done.

To set up the AuGeo application, the user needed to be logged in with the same AGOL account that the desired feature service was stored in. If the feature service was public, then any AGOL account can be used. After logging in, the next step was to download the feature service. To download the feature service, there was a button in the top right that, when clicked, brings the user to another menu. One option in that menu was “download data.” Clicking this option might prompt the user to login in again, but after that, the features in the organization with the “AuGeo” tag were present. For this project the “transformers” layer was selected and downloaded.

After the data was downloaded, it needed to be configured slightly in the application. The viewing distance needed to be adjusted as the default was too small of a distance. The default viewing distance was changed to 500ft in the same menu that the data was downloaded in.

Now that the application and data was all set up, it was time to use the application. Viewing the data needed to be done outside, to allow the devices GPS to work unobstructed. After the phones GPS had calibrated, little pop ups on the cameras view appear; an example is shown in Figure 5-11.

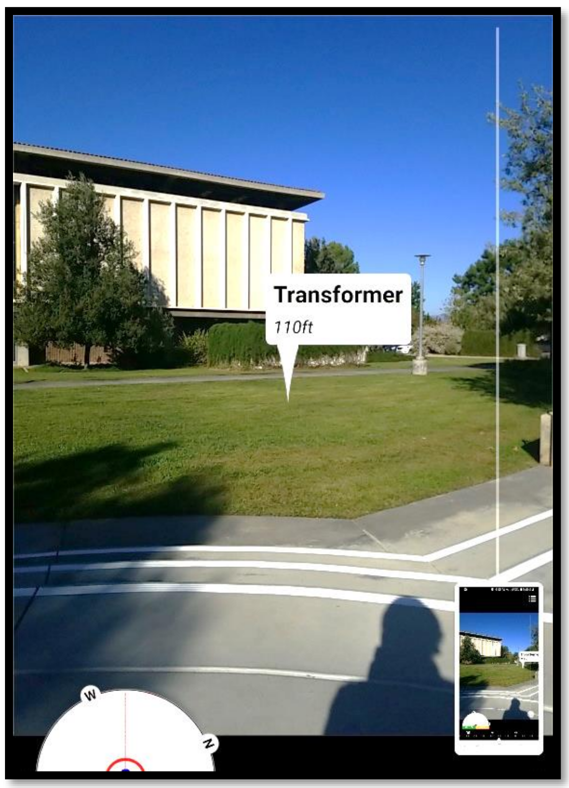

Figure 5-11: Screenshot of AuGeo application. There is a transformer 110ft from the user.

5.5 Summary

This chapter detailed how the different deliverables for this project were accomplished. Section 5.1 went through the background setup that needed to be done before any the specific project work could be done; this included transferring the data into a new geodatabase and publishing the feature layers to AGOL. The next section 5.2 discussed the process for how the Survey123 applications were created and the configuration process in Survey123 Connect. Following the survey creations, section 5.3 was discussed. Section 5.3 talked about the cleanup process for the existing data, the cleaning up of the linework and finished by talking about adding all the missing service points. Section 5.4 was the final section and it went through the set up process for the AR application, AuGeo.

Chapter 6 – Results

This chapter will discuss the results from the project. It will also talk about how the client's deliverables were met. It will depict what areas that challenges were encountered. The issues found in the project, and possible solutions, that were outside of the scope this project will be suggested will also be addressed.

6.1 Survey123 Results

The City of Aspen's electric department wanted a way to easily update its electric distribution network. Since the electric department staff have limited GIS knowledge, it was agreed that the best way for them to update their assets would be through a mobile application. Esri's Survey123 was selected to be used as it allowed for both the adding of new points and the editing of existing points via preexisting feature classes.

A total of eight surveys were created. These surveys were based off existing feature classes that already had data populated for them. Each survey had its own Excel spreadsheet that held all the information about what fields were to be displayed, domain information, labeling and any default values. These excel spreadsheets can be seen in Appendix D.

6.2 Survey123 Limitations

There were two main limitations that were identified during the creation of the Survey123 applications. The first was how Survey123 interacted with line feature classes, and the second was transferring the ownership of the surveys to the client.

Survey123 allows you to create a survey using a line feature class, initially the set up appears to work the same as creating a survey from a point feature class. The electric department only has two line feature classes; primary and secondary underground lines. When the surveys for these two feature classes were configured and published in the same manner as the line feature classes, it was discovered that Survey123 couldn't draw the existing feature classes on the map in the application. It would instead default the maps location to a random location somewhere in the world. The survey however had all the lines populated in them, they just wouldn't show up in the map. After some research on Esri's GeoNet, it was discovered that editing existing line and polygon feature classes is not supported currently in Survey123 (Rcigliczr, 2017)

Since the functionality of these applications wasn't working and there wasn't any way to get around this issue and still utilize Survey123, it was decided that the two line feature classes would be removed as a deliverable.

A solution that would allow the City of Aspen's electric department to collect line feature class information in the field would be to use the Collector application from Esri. Collector allows the user to collect line, points and polygon features. Collector has its limitations though; for example it is mainly aimed at collecting new data and therefore the editing of existing data is not as user friendly as Survey123.

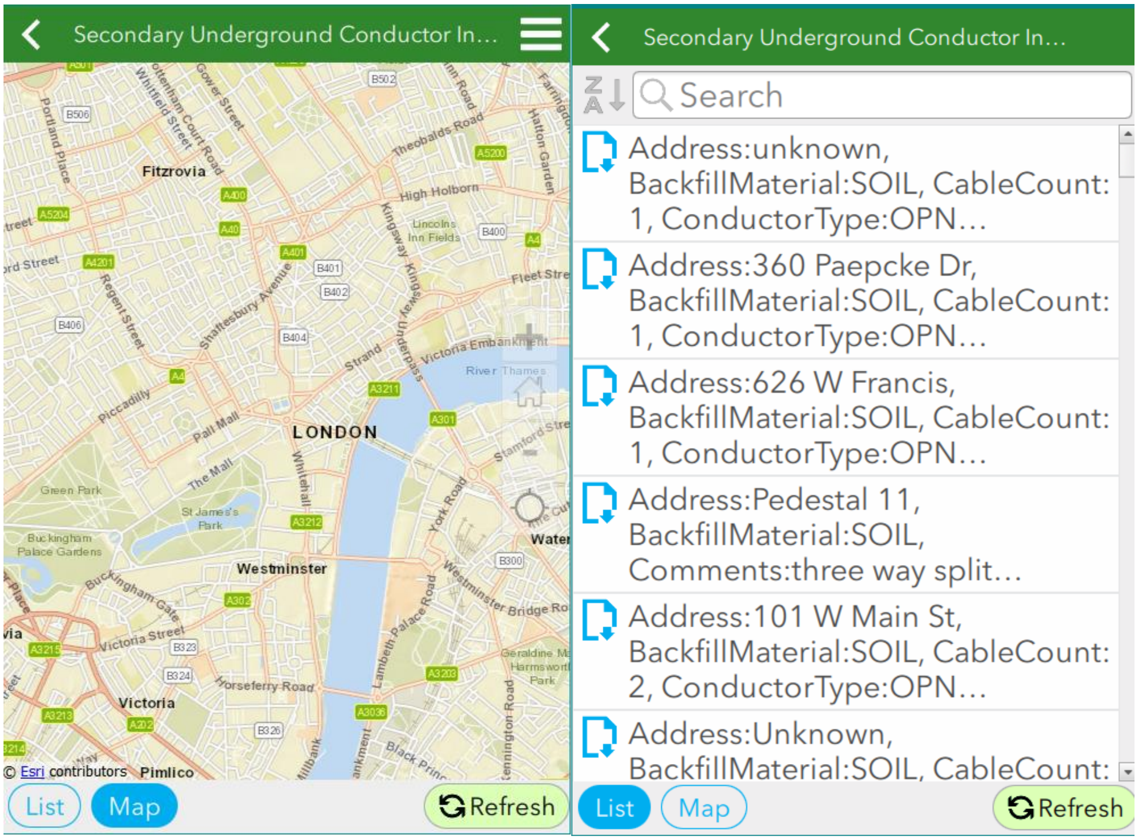

Figure 6-1: The screenshot on the left showing the lack of line feature classes. The right is the same survey, showing that the data has been loaded.

A second limitation with Survey123 was discovered when the surveys were ready to be delivered to the client. When a survey is created, a corresponding Excel spreadsheet is formed and saved onto the user's computer. However, there is no way to change the path location that it is saved to. In multiple Esri products you can simply change the path's link to change the ownership. This isn't possible in Survey123. The only solution was for the client to have the applications rebuilt on their own device. Although this only required creating a new survey and copying and pasting the original Excel spreadsheets it was still something that shouldn't have had to be done. The reason that the spreadsheets needed to be on the client's device was in case they ever need to reconfigure any of the fields that they want to collect data for.

6.3 Geodatabase Integrity Results

The second deliverable for the project was to improve the integrity of the existing data. There were many topology errors in the data and the linework was often hard to follow. The client wanted these issues to be resolved.

The topology errors were successfully fixed. As the existing geodatabase had a Geometric Network built into it, there were net junctions that were automatically populated. A net junction identifies where a Geometric Network rule is being broken. Most of the broken rules were missing service points, and lines that were broken into multiple individual sections. The lines were merged to only have one segment between point features. There were originally 930 primary underground lines; after the merging there was only 302. Service points were also added to the network; each secondary line should have an associated service point at its end. Prior to the cleanup, there was 343 service points and after the cleanup there was 619, which matched the number of secondary lines. There were 7 net junctions that were unable to be resolved. These were special, complicated places on the network that didn't follow standard electric conventions, or were showing where the electricity was coming into the city's network.

This portion of the project went well, and the client now has a topologically correct network. There are still many attributes missing for the assets but that is something that couldn't be solved without going into the field. The electric department will be able to work on that with its Survey123 applications.

The other component of the data integrity cleanup portion was adjusting the line work to make it clearer to read. The original data had lots of overlapping lines and irregular angles. The electric department wanted the linework to be cleaner to look at, which in turn also makes it easier to follow. The spatial location of the lines was not accurate, it was representative, therefore moving the linework to make it easy to read was not compromising its positional accuracy. Figure 6-2 shows a portion of the network both before and after the linework was corrected.

The end deliverable for this portion of the project was a web map. The web map has custom symbology that was created by both comparing the City of Aspen's old electric web map and looking at other organization's electric distribution networks.

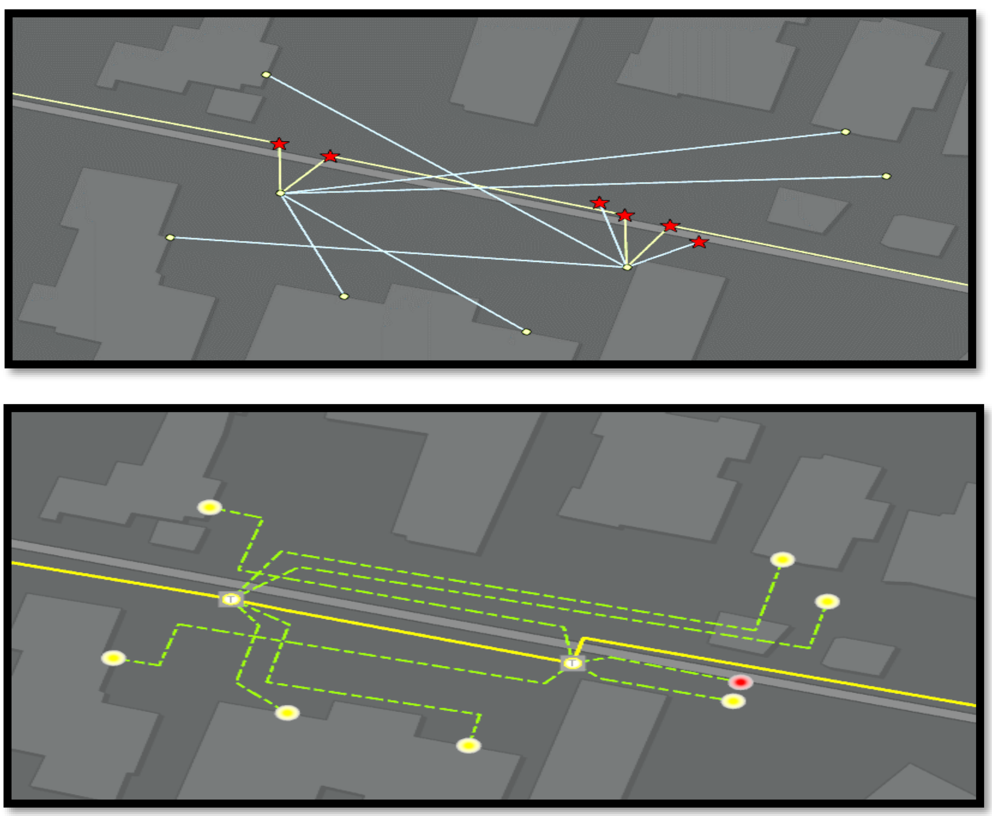

Figure 6-2: A before and after of the adjusted linework.

6.4 Web Map Issues

During the creation of the web map there was a minor issue that was encountered. In ArcGIS Pro there is the option to publish the map as a web map to ArcGIS Online (AGOL). This method is how the client had originally suggested to publish the web map. Therefore, the web map was configured in ArcGIS Pro; the scale dependencies were set, and the pop-ups were configured. When the map was ready, it was published. It appeared to publish successfully but after reviewing the web map it was discovered that although every feature class was present, multiple of feature classes had empty attribute tables. Interestingly after talking with the client about this issue, they had also experienced this bug with a different project's web map.

After some troubleshooting, a workaround was discovered. To ensure that all of the feature classes published correctly, they were published individually. Then after all the layers had been published, the web map was then created in AGOL. The pop-ups and scale dependencies were reset. This took a little longer to create, but it looked and functioned the same as the original web map and had all the correct data.

6.5 AuGEO Results

AuGEO is an Augmented Reality (AR) application that's aim was to allow the electric department to view information about its electric network through a smart device's camera. Configuring AuGEO was straightforward and didn't cause any issues. A pilot model was made with some data created on the University of Redlands campus. This application worked and a screenshot (Figure 6-3) can be seen below.

Figure 6-3: A screenshot of a pilot test of AuGEO at the University of Redlands.

However, when the application was implemented in Aspen it did not work accurately. The application appeared to be working due to the camera displaying pop-ups for transformer locations, but their spatial accuracy was not correct. For example, a transformer was tested and from every possible angle, and the camera could not place the correct pop up; it was always off the screen. There are a few reasons why this could have happened. One is interference from buildings and the mountains which could have blocked the phone from getting a clear signal. Related to that issue was the thought that the actual GPS in the phone was not very accurate. As discussed in the Chapter 2 the accuracy in phones GPS are a huge limitation as to how accurate an AR application can be. A way to test this issue would be to pair the phone with an external GPS and see if that makes a difference.

6.6 AuGEO Limitations

After using AuGEO there were a few limitations that were discovered with the application. The biggest limitation was the fact that it can only accept a single feature class that has to be point data. The original concept was to create an AR application that would allow the user to view the entire electric distribution network as it lies underground. This was not possible with AuGEO.

The other limitation that was discovered with AuGEO was what information could be displayed. When the AGOL layer is configured the pop-up is configured, however the only part of the pop-up that AuGEO can show is the title. This drastically limits that number of attributes that can be displayed. In reality, only one or two attributes can be displayed. This makes the practicality and usefulness of the application significantly less.

Due to the limitations of the AuGEO application and the problems with GPS calibrations, it was concluded that AuGEO is not good for showing utility data. It is best for a simple, point layer application. Even though AuGEO did not work as originally desired, it does leave room for a lot of improvements with what could be done with AR and utilities in the future. Some future suggestions are discussed in section 7.2.

Chapter 7 – Conclusions and Future Work

This chapter will start by briefly describing the client's problem and how it was successfully solved. There will also be a few suggestions for how this project could be expanded upon for future work.

7.1 Project Summary

This project looked at how GIS can be used for managing electric utility assets. The client for the project was the City of Aspen, a small local government located in Colorado. The electric distribution network in Aspen is a small, underground network that had historically only been truly understood by a few individuals. These individuals are closing in on retirement, providing a push to migrate the electric distribution network into a reliable format. Therefore a few years ago, the city decided to start recording its electric assets in GIS. The problem was that although they had implemented a GIS database of their electric assets, there were many incorrectly placed features and many attribution issues. In 2019, the city wants to migrate all of its utility assets (water, storm water and electric) into the Utility Network (UN) from Esri. Before the electric distribution network was ready for this migration, work needed to be done to its existing electric network. This problem is what this project addressed.

To solve the issue of having an incomplete geodatabase, mobile data collection applications were created. The applications were built using Esri's Survey123 program. These applications allowed the electric department to add new features and also edit existing features, all from their phones when out in the field.

In addition to collecting new data and attributes, the existing data also needed to be cleaned up. There were many topology errors; these were fixed. Once the topology was fixed the linework was adjusted to allow for an easier to follow network. Custom symbology was added to help the electric department distinguish between the different assets with ease.

The final component of this project was the creation of an Augmented Reality (AR) application. This application was built to work on mobile devices and it used the AuGEO program from Esri. The application allows the electric department to see information and the location of transformers through their phones' cameras.

7.2 Future Work

The beauty with utility asset management using GIS is that there is an endless amount of areas that can be utilized for future expansion. The following section will discuss some of these possible expansions.

One area in which the City of Aspen's electric department has underutilized the power of GIS, is its analysis capabilities. Once their network has been migrated into the UN, the electric department could perform analysis on the network. A great example is analyzing the flow of power through the network. It would be possible to see what transformers have the highest load and, vice versa, the lowest load. Knowing these facts can help them understand what areas are more susceptible to outages or which transformers are being underutilized.

Another analysis that could be run on the network would be one to help the electric department during an outage; this could be set up in an Operations Dashboard and could pin point a location that is experiencing an outage, then do a trace up the network to find the transformer that is not operating correctly. In addition to knowing which transformer is possibly causing the outage, it would also allow the electric department to know what other customers are also out of power due to the faulty transformer. Figure 7-1 shows how an organization is using Operations Dashboard to track outages in their network.

Figure 7-1: An Operations Dashboard showing how an organization manages network outages (Bell, 2016).

A really interesting and exciting future project would be to create a more advanced AR application. It would be fascinating to be able to view the entire electric network as it lays underground. If the actual location of the lines were spatially accurate, it could potentially save the city money and time, as digging for a utility locate prior to construction projects wouldn’t be needed. In addition to just having the electric network in an AR application, if all the underground assets could be incorporated into one program, it would allow for a really useful tool. Figure 7-2 shows how an organization is utilizing AR technology to view their underground assets.

Figure 7-2: A image of how an organization is utilizing AR technology to view their underground assets (VGIS, 2018).

Aspen also has a storm water network that is in its initial stages of utilizing GIS. Both the data collection applications and the data integrity portions of this project could be applied to building a detailed storm water geodatabase.

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Appendix A. Utilized Fields in ArcGIS Pro

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓	AncillaryRoleDomain	None	
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		8	
FacilityID	Facility ID	Text	✓			20
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
OperatingVoltage	Operating Voltage	Long	✓	Electric Device Operating Voltage Single		
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Hyperlink	Hyperlink	Text	✓			255
NominalVoltage	NominalVoltage	Long	✓			
MaxContinuousCurrent	Maximum Continuous Current	Double	✓	Over Current Prot Dev Max Continuous Current	200 A	
MaxInterruptingCurrent	Maximum Interrupting Current	Double	✓	Over Current Prot Dev Max Interrupting Current	8 kA	
MaxOperatingVoltage	Maximum Operating Voltage	Long	✓	Max Operating Voltage	7.2/12.4 kV	
NormalPosition_A	Normal Position - A	Long	✓	Normal Status	Closed	
NormalPosition_B	Normal Position - B	Long	✓	Normal Status	Closed	
NormalPosition_C	Normal Position - C	Long	✓	Normal Status	Closed	
PresentPosition_A	Present Position - A	Long	✓	Present Status	Closed	
PresentPosition_B	Present Position - B	Long	✓	Present Status	Closed	
PresentPosition_C	Present Position - C	Long	✓	Present Status	Closed	
LabelText	Label Text	Text	✓			50
PhaseDesignation	Phase Designation	Long	✓			
BILRating	BIL Rating	Long	✓	BIL Rating	110 BIL	
BypassSwitch	Bypass Switch	Text	✓			5
ClosingResistor	Closing Resistor	Text	✓			5
GangOperated	Gang Operated Indicator	Text	✓			5
GroundResistance	Ground Resistance	Double	✓			
InterruptingMechanism	Interrupting Mechanism	Text	✓			20
InterruptingMedium	Interrupting Medium	Text	✓	Interrupting Medium	Oil	5
MountingType	Mounting Type	Text	✓			5
SCADAControlID	SCADA Control ID	Text	✓			20
SCADAMonitorID	SCADA Monitor ID	Text	✓			20
ShuntMechanism	Shunt Mechanism	Text	✓			20
TieSwitchIndicator	Tie Switch Indicator	Text	✓			5
TripCount	Trip Count	Long	✓			
Manufacturer	Manufacturer	Text	✓			25
Model	Model	Text	✓			20
SerialNumber	Serial Number	Text	✓			20
SupportStructureObjectID	SupportStructureObjectID	Long	✓			
HFrameObjectID	H Frame ObjectID	Long	✓			
ElectricStationObjectID	Electric Station ObjectID	Long	✓			
SwitchingFacilityObjectID	Switching Facility ObjectID	Long	✓			
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
NOCANSPERPHASE	NOCANSPERPHASE	Text	✓			50
FUSESIZE	FUSESIZE	Text	✓			50

Appendix 1: Dynamic Protective Device Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		1	
FacilityID	Facility ID	Text	✓			20
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
OperatingVoltage	Operating Voltage	Long	✓	Electric Device Operating Voltage Single		
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Hyperlink	Hyperlink	Text	✓			255
NominalVoltage	NominalVoltage	Long	✓			
MaxContinuousCurrent	Maximum Continuous Current	Double	✓	Over Current Prot Dev Max Continuous Current	200 A	
MaxInterruptingCurrent	Maximum Interrupting Current	Double	✓	Over Current Prot Dev Max Interrupting Current	8 kA	
MaxOperatingVoltage	Maximum Operating Voltage	Long	✓	Max Operating Voltage	7.2/12.4 kV	
NormalPosition_A	Normal Position - A	Long	✓	Normal Status	Closed	
NormalPosition_B	Normal Position - B	Long	✓	Normal Status	Closed	
NormalPosition_C	Normal Position - C	Long	✓	Normal Status	Closed	
PresentPosition_A	Present Position - A	Long	✓	Present Status	Closed	
PresentPosition_B	Present Position - B	Long	✓	Present Status	Closed	
PresentPosition_C	Present Position - C	Long	✓	Present Status	Closed	
LabelText	Label Text	Text	✓			50
PhaseDesignation	Phase Designation	Long	✓	Phase Designation	A	
SupportStructureObjectID	SupportStructureObjectID	Long	✓			
HFrameObjectID	HFrame Object ID	Long	✓			
ElectricStationObjectID	Electric Station ObjectID	Long	✓			
SwitchingFacilityObjectID	Switching Facility ObjectID	Long	✓			
UndergroundStructureObjectID	Underground Structure ObjectID	Long	✓			
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINCLASS	Text	✓			50
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
Amperage	Amperage	Text	✓			50

Appendix 2: Fuse Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		1	
MeasuredLength	Measured Length	Double	✓	Measured Length		
LengthSource	Length Source	Text	✓	Length Source Indicator	Mapping System	5
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
Comments	Comments	Text	✓			255
Hyperlink	Hyperlink	Text	✓			255
PhaseDesignation	Phase Designation	Long	✓			
NominalVoltage	Nominal Voltage	Long	✓			
OperatingVoltage	Operating Voltage	Long	✓	Electric Line Voltage		
ConductorType	Conductor Type	Text	✓	Conductor Type	Open Wire	5
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
NeutralMaterial	Neutral Material	Text	✓	Neutral Material		5
NeutralSize	Neutral Size	Text	✓	Neutral Size		5
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
LabelText	Label Text	Text	✓			50
BackfillMaterial	Backfill Material	Text	✓	Backfill Material	Soil	5
BuriedDepth	Buried Depth	Double	✓			
CableCount	Cable Count	Long	✓	Cable Count	1	
InConduitIndicator	In Conduit Indicator	Text	✓	Yes/No Indicator	No	5
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
ConduitType	Conduit Type	Text	✓			50
CouduitSize	Couduit Size	Long	✓			
Conduit_Type		Text	✓			50
Conduit_Size		Long	✓			
SHAPE_Length		Double	✓			

Appendix 3: Primary Underground Line Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		1	
MeasuredLength	Measured Length	Double	✓	Measured Length		
LengthSource	Length Source	Text	✓	Length Source Indicator	Mapping System	5
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
Comments	Comments	Text	✓			255
Hyperlink	Hyperlink	Text	✓			255
PhaseDesignation	Phase Designation	Long	✓			
NominalVoltage	Nominal Voltage	Long	✓			
OperatingVoltage	Operating Voltage	Long	✓	Electric Line Voltage		
ConductorType	Conductor Type	Text	✓	Conductor Type	Open Wire	5
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
NeutralMaterial	Neutral Material	Text	✓	Neutral Material		5
NeutralSize	Neutral Size	Text	✓	Neutral Size		5
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
LabelText	Label Text	Text	✓			50
BackfillMaterial	Backfill Material	Text	✓	Backfill Material	Soil	5
BuriedDepth	Buried Depth	Double	✓			
CableCount	Cable Count	Long	✓	Cable Count	1	
InConduitIndicator	In Conduit Indicator	Text	✓	Yes/No Indicator	Yes	5
ServiceIndicator	Service Indicator	Text	✓			5
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
RUN_Count		Long	✓			
Address		Text	✓		Unknown	100
SHAPE_Length		Double	✓			

Appendix 4: Secondary Underground Line Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		1	
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
LocationID	Location ID	Text	✓			20
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Comments	Comments	Text	✓			255
Hyperlink	Hyperlink	Text	✓			255
PhaseDesignation	Phase Designation	Long	✓	Phase Designation	A	
Address	Address	Text	✓			50
ConnectionType	Connection Type	Text	✓			20
ServiceCurrentRating	Service Current Rating	Short	✓	Service Current Rating	200 A	
AlternateX	Alternate - X	Double	✓			
AlternateY	Alternate - Y	Double	✓			
AlternateZ	Alternate - Z	Double	✓			
AlternateSource	Alternate Source	Text	✓	Feature Source		5
Status	Status	Text	✓	Active Indicator	Active	5
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
TRANSFORMER_OH_OBJECTID	TRANSFORMER_OH_OBJECTID	Long	✓			
TRANSFORMER_UG_OBJECTID	TRANSFORMER_UG_OBJECTID	Long	✓			

Appendix 5: Service Point Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
Hyperlink	Hyperlink	Text	✓			255
***SubtypeCD**	Subtype	Long	✓		3	
FacilityID	Facility ID	Text	✓			20
Owner	Owner	Text	✓			20
AlternateX	Alternate - X	Double	✓			
AlternateY	Alternate - Y	Double	✓			
AlternateZ	Alternate - Z	Double	✓			
AlternateSource	Alternate Source	Text	✓	Feature Source		5
SymbolRotation	Symbol Rotation	Double	✓		0	
Material	Material	Text	✓			5
Name	Name	Text	✓			20
StructureSize	Structure Size	Text	✓			20
Manufacturer	Manufacturer	Text	✓			20
Model	Model	Text	✓			20
ROUTENUMBER	ROUTENUMBER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
Enabled	Enabled	Short	✓	EnabledDomain	True	

Appendix 6: Surface Structure (Pedestal) Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		4	
FacilityID	Facility ID	Text	✓			20
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
OperatingVoltage	Operating Voltage	Long	✓	Electric Device Operating Voltage Single		
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Hyperlink	Hyperlink	Text	✓			255
NominalVoltage	NominalVoltage	Long	✓			
PhaseDesignation	Phase Designation	Long	✓			
ManuallyOperated	Manually Operated Indicator	Text	✓			5
MaxContinuousCurrent	Maximum Continuous Current	Double	✓			
MaxOperatingVoltage	Maximum Operating Voltage	Long	✓	Max Operating Voltage	7.2/12.4 kV	
NormalPosition_A	Normal Position - A	Long	✓	Normal Status	Closed	
NormalPosition_B	Normal Position - B	Long	✓	Normal Status	Closed	
NormalPosition_C	Normal Position - C	Long	✓	Normal Status	Closed	
PresentPosition_A	Present Position - A	Long	✓	Present Status	Closed	
PresentPosition_B	Present Position - B	Long	✓	Present Status	Closed	
PresentPosition_C	Present Position - C	Long	✓	Present Status	Closed	
TieSwitchIndicator	Tie Switch Indicator	Text	✓			5
SCADAControlID	SCADA Control ID	Text	✓			20
SCADAMonitorID	SCADA Monitor ID	Text	✓			20
PreferredCircuitSource	Preferred Circuit Source	Text	✓			20
LabelText	Label Text	Text	✓			50
SupportStructureObjectID	SupportStructureObjectID	Long	✓			
GangOperated	Gang Operated Indicator	Text	✓			5
HFrameObjectID	H Frame ObjectID	Long	✓			
SwitchingFacilityObjectID	Switching Facility ObjectID	Long	✓			
UndergroundStructureObjectID	Underground Structure ObjectID	Long	✓			
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
Normally_Open	Normally_Open	Text	✓	Yes/No Indicator		50

Appendix 7: Switch Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
Hyperlink	Hyperlink	Text	✓			255
*SubtypeCD	Subtype	Long	✓		3	
FacilityID	Facility ID	Text	✓			20
Owner	Owner	Text	✓			20
AlternateX	Alternate - X	Double	✓			
AlternateY	Alternate - Y	Double	✓			
AlternateZ	Alternate - Z	Double	✓			
AlternateSource	Alternate Source	Text	✓	Feature Source		5
SymbolRotation	Symbol Rotation	Double	✓		0	
NominalVoltage	Nominal Voltage	Long	✓	Switch Nominal Voltage	13.8 kV	
Configuration	Configuration	Text	✓			20
Manufacturer	Manufacturer	Text	✓			20
Model	Model	Text	✓			20
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
Enabled	Enabled	Short	✓	EnabledDomain	True	

Appendix 8: Switching Facility Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		3	
FacilityID	Facility ID	Text	✓			20
FeederID	Feeder ID	Text	✓			20
FeederID2	Feeder ID 2	Text	✓			20
OperatingVoltage	Operating Voltage	Long	✓	Electric Device Operating Voltage Single		
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
Comments	Comments	Text	✓			255
ElectricTraceWeight	Electric Trace Weight	Long	✓			
FeederInfo	Feeder Information	Long	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Hyperlink	Hyperlink	Text	✓			255
NominalVoltage	NominalVoltage	Long	✓			
GroundReactance	Ground Reactance	Long	✓			
GroundResistance	Ground Resistance	Long	✓			
HighSideGroundReactance	High Side Ground Reactance	Long	✓			
HighSideGroundResistance	High Side Ground Resistance	Long	✓			
HighSideProtection	High Side Protection	Text	✓	Transformer Bank High Side Protection		5
LocationType	Location Type	Text	✓	Location Type	Service Point	5
MagnetizingReactance	Magnetizing Reactance	Double	✓			
MagnetizingResistance	Magnetizing Resistance	Double	✓			
LabelText	Label Text	Text	✓			100
PhaseDesignation	Phase Designation	Long	✓			
HighSideConfiguration	High Side Configuration	Text	✓			5
LowSideConfiguration	Low Side Configuration	Text	✓			5
LoadTapChangerIndicator	Load Tap Changer Indicator	Text	✓			5
LowSideGroundReactance	Low Side Ground Reactance	Double	✓			
LowSideGroundResistance	Low Side Ground Resistance	Double	✓			
LowSideProtection	Low Side Protection	Text	✓			20
LowSideVoltage	Low Side Voltage	Long	✓			
FilledWeight	Filled Weight	Double	✓			
EmptyWeight	Empty Weight	Double	✓			
HeightBushings	Height with Bushings	Double	✓			
HeightNoBushings	Height without Bushings	Double	✓			
RatedKVA65Rise	Rated kVA 65 Rise	Long	✓			
RatedTertiaryKVA	Rated Tertiary kVA	Long	✓			
SwitchType	Switch Type	Text	✓			20
TertiaryConfiguration	Tertiary Configuration	Text	✓			20
TertiaryVoltage	Tertiary Voltage	Long	✓			
AlternateX	Alternate - X	Double	✓			
AlternateY	Alternate - Y	Double	✓			
AlternateZ	Alternate - Z	Double	✓			
AlternateSource	Alternate Source	Text	✓	Feature Source		5
SupportStructureObjectID	SupportStructureObjectID	Long	✓			
HFrameObjectID	HFrameObjectID	Long	✓			
SurfaceStructureObjectID	Surface Structure ObjectID	Long	✓			
ElectricStationObjectID	Electric Station ObjectID	Long	✓			
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50
CONSTRUCTIONTYPE	CONSTRUCTIONTYPE	Text	✓			50
Model_Make	Model/Make	Text	✓			250
Secondary_Address_Location	Secondary Address/Location	Text	✓			250
Rated_kVA	Rated kVA	Long	✓			
PercentImpedance	PercentImpedance	Float	✓			
SecondaryVoltage	Secondary Voltage	Text	✓			50
Phase	Phase Designation	Text	✓			255

Appendix 11: Transformer Feature Class

Field Name	Alias	Data Type	Allow NULL	Domain	Default	Length
OBJECTID	OBJECTID	Object ID				
SHAPE	SHAPE	Geometry	✓			
AncillaryRole	AncillaryRole	Short	✓			
Enabled	Enabled	Short	✓	EnabledDomain	True	
CreationUser	Creation User	Text	✓			50
DateCreated	Date Created	Date	✓			
LastUser	Last User	Text	✓			50
DateModified	Date Modified	Date	✓			
***SubtypeCD**	Subtype	Long	✓		2	
FacilityID	Facility ID	Text	✓			20
Material	Material	Text	✓			20
StructureSize	Structure Size	Text	✓			20
StructureType	Structure Type	Text	✓			20
Manufacturer	Manufacturer	Text	✓			20
Model	Model	Text	✓			20
Comments	Comments	Text	✓			255
ConstructionStatus	Construction Status	Long	✓	Construction Status	Existing	
WorkOrderID	Work Order ID	Text	✓			20
InstallationDate	Installation Date	Date	✓			
SymbolRotation	Symbol Rotation	Double	✓		0	
Hyperlink	Hyperlink	Text	✓			255
FacilityDiagram	Facility Diagram	Text	✓	Yes/No Indicator		255
ROUTENUMBER	ROUTENUMBER	Text	✓			50
OWNER	OWNER	Text	✓			50
OPERATINGCLASS	OPERATINGCLASS	Text	✓			50

Appendix 10: Underground Structure Feature Class

Appendix B. Script to Write All Domains from a Geodatabase

```
import arcpy

domains = arcpy.da.ListDomains("C:/Users/Hamish Henderson/Documents/MIP_DATA/6-

for domain in domains:
    print('Domain name: {0}'.format(domain.name))
    if domain.domainType == 'CodedValue':
        coded_values = domain.codedValues
        for val, desc in coded_values.items():
            print('{0} : {1}'.format(val, desc))
    elif domain.domainType == 'Range':
        print('Min: {0}'.format(domain.range[0]))
        print('Max: {0}'.format(domain.range[1]))

```

Appendix C. Fields Not Needed for Aspen's Electric Distribution Network

Switch Load Break	Pedestal	Open Point
Construction Status	Name	Electric Trace Weight
Work Order ID	Structure Size	Feeder ID
Electric Trace Weight	Manafacture	Feeder ID 2
Feeder ID 2	Model	Symbol Rotation
Symbol Rotation	Route Number	Hyperlink
Hyperlink	Operating Class	Model
Tie Switch Indicator	Symbol Rotation	Voltage Regulator Object ID
Label Text	Construction Status	Surface Structure Object ID
Support Structure Object ID	Work Order ID	Surface Structure Object ID
H Frame Object ID	Hyperlink	Surface Structure Object ID
Switching Facility Object ID	Enabled	Surface Structure Object ID
Underground Structure Object ID		Surface Structure Object ID
		Surface Structure Object ID
		Surface Structure Object ID

Transformers	Transformers2	Service Points
Magnetizing Reactance	Tertiary Voltage	Feeder ID
Magnetizing Resistance	Support Structure Object ID	Feeder ID 2
Label Text	H Frame ObjectID	Location ID
Low Side Ground Reactance	Surface Structure ObjectID	Work Order ID
Low Side Ground Resistance	Electric Station ObjectID	Electric Trace Weight
Low Side Voltage	Enabled	Symbol Rotation
Low Side Protection	Electric Trace Weight	Hyperlink
Empty Weight	Feeder ID	Alternate X
Height with Bushings	Feeder ID 2	Alternate Y
Height without Bushings	Hyperlink	Alternate Z
Rated kVA 65 Rise	Nominal Voltage	Transformer OH Object ID
Rated Tertiary kVA	Ground Reactance	
Tertiary Configuration	Ground Resistance	
High Side Ground Resistance	High Side Ground Reactance	

Dynamic Protective Device	Fuse	Splice Vault
Feeder ID 2	Feeder ID 2	Construction Status
Work Order ID	Construction Status	Work Order ID
Electric Trace Weight	Work Order ID	Symbol Rotation
Symbol Rotation	Electric Trace Weight	Facility Diagram
Hyperlink	Symbol Rotation	Route Number
Label Text	Hyperlink	
BIL Rating	Label Text	
Closing Resistor	Support Structure Object ID	
Interrupting Medium	H Frame Object ID	
Tie Switch Indicator		
Support Structure Object ID		
H Frame Object ID		
Vocansper Phase		

Appendix D. Survey123 Excel Files

1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one EnabledDomain	Enabled	Enabled	1	esriFieldTypeSmallInteger	
5	select_one SubtypeCD	SubtypeCD	Subtype	1	esriFieldTypeInteger	
6	select_one PhaseDesignation	PhaseDesignation	Phase Designation		esriFieldTypeInteger	
7	text	FacilityID	Facility ID		esriFieldTypeString	20
8	text	FeederID	Feeder ID		esriFieldTypeString	20
9	select_one ElectricDeviceOperatingVoltageSingle	OperatingVoltage	Operating Voltage		esriFieldTypeInteger	
10	select_one ConstructionStatus	ConstructionStatus	Construction Status	5	esriFieldTypeInteger	
11	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
12	text	Comments	Comments		esriFieldTypeString	255
13	integer	FeederInfo	Feeder Information		esriFieldTypeInteger	
14	integer	NominalVoltage	NominalVoltage		esriFieldTypeInteger	
15	select_one OverCurrentProtDevMaxContinuousCurrent	MaxContinuousCurrent	Maximum Continuous Current	200	esriFieldTypeDouble	
16	select_one OverCurrentProtDevMaxInterruptingCurrent	MaxInterruptingCurrent	Maximum Interrupting Current	8000	esriFieldTypeDouble	
17	select_one MaxOperatingVoltage	MaxOperatingVoltage	Maximum Operating Voltage	210	esriFieldTypeInteger	
18	select_one NormalStatus	NormalPosition_A	Normal Position - A	1	esriFieldTypeInteger	
19	select_one NormalStatus	NormalPosition_B	Normal Position - B	1	esriFieldTypeInteger	
20	select_one NormalStatus	NormalPosition_C	Normal Position - C	1	esriFieldTypeInteger	
21	select_one PresentStatus	PresentPosition_A	Present Position - A	1	esriFieldTypeInteger	
22	select_one PresentStatus	PresentPosition_B	Present Position - B	1	esriFieldTypeInteger	
23	select_one PresentStatus	PresentPosition_C	Present Position - C	1	esriFieldTypeInteger	
24	text	BypassSwitch	Bypass Switch		esriFieldTypeString	5
25	text	GangOperated	Gang Operated Indicator		esriFieldTypeString	5
26	decimal	GroundResistance	Ground Resistance		esriFieldTypeDouble	
27	text	InterruptingMechanism	Interrupting Mechanism		esriFieldTypeString	20
28	text	MountingType	Mounting Type		esriFieldTypeString	5
29	text	SCADAControlID	SCADA Control ID		esriFieldTypeString	20
30	text	SCADAMonitorID	SCADA Monitor ID		esriFieldTypeString	20
31	text	ShuntMechanism	Shunt Mechanism		esriFieldTypeString	20
32	integer	TripCount	Trip Count		esriFieldTypeInteger	
33	text	Manufacturer	Manufacturer		esriFieldTypeString	25
34	text	Model	Model		esriFieldTypeString	20
35	text	SerialNumber	Serial Number		esriFieldTypeString	20
36	integer	ElectricStationObjectID	Electric Station ObjectID		esriFieldTypeInteger	
37	integer	SwitchingFacilityObjectID	Switching Facility ObjectID		esriFieldTypeInteger	
38	text	OWNER	Owner	City of Aspen	esriFieldTypeString	50
39	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString	50
40	text	CONSTRUCTIONTYPE	Construction Type		esriFieldTypeString	50
41	text	FUSESIZE	Fuse Size		esriFieldTypeString	50
42	text	CreationUser	Creation User		esriFieldTypeString	50
43	dateTime	DateCreated	Date Created		esriFieldTypeDate	
44	text	LastUser	Last User		esriFieldTypeString	50
45	dateTime	DateModified	Date Modified		esriFieldTypeDate	
46	image	Attachment	Attachment			

Appendix 11: Dynamic Protective Device

1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one EnabledDomain	Enabled	Enabled	1	esriFieldTypeSmallInteger	
5	select_one SubtypeCD	SubtypeCD	Subtype	1	esriFieldTypeInteger	
6	select_one PhaseDesignation	PhaseDesignation	Phase Designation	4	esriFieldTypeInteger	
7	text	FacilityID	Facility ID		esriFieldTypeString	20
8	text	FeederID	Feeder ID		esriFieldTypeString	20
9	select_one ElectricDeviceOperatingVoltageSingle	OperatingVoltage	Operating Voltage		esriFieldTypeInteger	
10	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
11	text	Comments	Comments		esriFieldTypeString	255
12	integer	FeederInfo	Feeder Information		esriFieldTypeInteger	
13	integer	NominalVoltage	NominalVoltage		esriFieldTypeInteger	
14	text	Amperage	Amperage		esriFieldTypeString	50
15	select_one OverCurrentProtDevMaxContinuousCurrent	MaxContinuousCurrent	Maximum Continuous Current	200	esriFieldTypeDouble	
16	select_one OverCurrentProtDevMaxInterruptingCurrent	MaxInterruptingCurrent	Maximum Interrupting Current	8000	esriFieldTypeDouble	
17	select_one MaxOperatingVoltage	MaxOperatingVoltage	Maximum Operating Voltage	210	esriFieldTypeInteger	
18	select_one NormalStatus	NormalPosition_A	Normal Position - A	1	esriFieldTypeInteger	
19	select_one NormalStatus	NormalPosition_B	Normal Position - B	1	esriFieldTypeInteger	
20	select_one NormalStatus	NormalPosition_C	Normal Position - C	1	esriFieldTypeInteger	
21	select_one PresentStatus	PresentPosition_A	Present Position - A	1	esriFieldTypeInteger	
22	select_one PresentStatus	PresentPosition_B	Present Position - B	1	esriFieldTypeInteger	
23	select_one PresentStatus	PresentPosition_C	Present Position - C	1	esriFieldTypeInteger	
24	integer	ElectricStationObjectID	Electric Station ObjectID		esriFieldTypeInteger	
25	integer	SwitchingFacilityObjectID	Switching Facility ObjectID		esriFieldTypeInteger	
26	integer	UndergroundStructureObjectID	Underground Structure ObjectID		esriFieldTypeInteger	
27	text	OWNER	Owner	City of Aspen	esriFieldTypeString	50
28	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString	50
29	text	CONSTRUCTIONTYPE	Construction Type		esriFieldTypeString	50
30	text	CreationUser	Creation User		esriFieldTypeString	50
31	dateTime	DateCreated	Date Created		esriFieldTypeDate	
32	text	LastUser	Last User		esriFieldTypeString	50
33	dateTime	DateModified	Date Modified		esriFieldTypeDate	
34	image	Attachment	Attachment			

Appendix 12: Fuse

1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one SubtypeCD	SubtypeCD	Subtype		esriFieldTypeInteger	
5	select_one PhaseDesignation	PhaseDesignation	Phase Designation		esriFieldTypeInteger	
6	text	FacilityID	Facility ID		esriFieldTypeString	20
7	select_one ElectricDeviceOperatingVoltageSingle	OperatingVoltage	Operating Voltage		esriFieldTypeInteger	
8	select_one ConstructionStatus	ConstructionStatus	Construction Status		esriFieldTypeInteger	
9	text	WorkOrderID	Work Order ID		esriFieldTypeString	20
10	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
11	text	Comments	Comments		esriFieldTypeString	255
12	integer	FeederInfo	Feeder Information		esriFieldTypeInteger	
13	integer	NominalVoltage	NominalVoltage		esriFieldTypeInteger	
14	text	Configuration	Configuration		esriFieldTypeString	20
15	select_one NormalStatus	NormalPosition_A	Normal Position - A		esriFieldTypeInteger	
16	select_one NormalStatus	NormalPosition_B	Normal Position - B		esriFieldTypeInteger	
17	select_one NormalStatus	NormalPosition_C	Normal Position - C		esriFieldTypeInteger	
18	select_one PresentStatus	PresentPosition_A	Present Position - A		esriFieldTypeInteger	
19	select_one PresentStatus	PresentPosition_B	Present Position - B		esriFieldTypeInteger	
20	select_one PresentStatus	PresentPosition_C	Present Position - C		esriFieldTypeInteger	
21	text	SpliceSize	Splice Size		esriFieldTypeString	5
22	text	Manufacturer	Manufacturer		esriFieldTypeString	20
23	integer	TransformerObjectID	Transformer ObjectID		esriFieldTypeInteger	
24	text	OWNER	Owner	City of Aspen	esriFieldTypeString	50
25	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString	50
26	text	CONSTRUCTIONTYPE	Construction Type		esriFieldTypeString	50
27	text	CreationUser	Creation User		esriFieldTypeString	50
28	dateTime	DateCreated	Date Created		esriFieldTypeDate	
29	text	LastUser	Last User		esriFieldTypeString	50
30	dateTime	DateModified	Date Modified		esriFieldTypeDate	
31	image	Attachment	Attachment			

Appendix 13: Open Point

1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	text	Comments	Comments		esriFieldTypeString	255
5	select_one SubtypeCD	SubtypeCD	Subtype	6	esriFieldTypeInteger	
6	text	FacilityID	Facility ID		esriFieldTypeString	20
7	text	Owner	Owner	City of Aspen	esriFieldTypeString	20
8	text	AlternateSource	Alternate Source		esriFieldTypeString	5
9	decimal	SymbolRotation	Symbol Rotation		esriFieldTypeDouble	
10	text	Material	Material		esriFieldTypeString	5
11	text	CreationUser	Creation User		esriFieldTypeString	50
12	dateTime	DateCreated	Date Created		esriFieldTypeDate	
13	text	LastUser	Last User		esriFieldTypeString	50
14	dateTime	DateModified	Date Modified		esriFieldTypeDate	
15	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
16	image	Attachment	Attachment			

Appendix 14: Pedestal

1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one EnabledDomain	Enabled	Enabled		esriFieldTypeSmallInteger	
5	text	Address	Address		esriFieldTypeString	50
6	select_one ActiveIndicator	Status	Status	A	esriFieldTypeString	5
7	select_one Subtype	SubtypeCD	Subtype	1	esriFieldTypeInteger	
8	select_one ServiceCurrentRating	ServiceCurrentRating	Service Current Rating		esriFieldTypeSmallInteger	
9	select_one PhaseDesignation	PhaseDesignation	Phase Designation		esriFieldTypeInteger	
10	select_one ConstructionStatus	ConstructionStatus	Construction Status		esriFieldTypeInteger	
11	text	Comments	Comments		esriFieldTypeString	255
12	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
13	integer	FeederInfo	Feeder Information		esriFieldTypeInteger	
14	text	CreationUser	Creation User		esriFieldTypeString	50
15	dateTime	DateCreated	Date Created		esriFieldTypeDate	
16	text	LastUser	Last User		esriFieldTypeString	50
17	dateTime	DateModified	Date Modified		esriFieldTypeDate	
18	text	ConnectionType	Connection Type		esriFieldTypeString	20
19	select_one FeatureSource	AlternateSource	Alternate Source		esriFieldTypeString	5
20	text	CONSTRUCTIONTYPE	Construction Type		esriFieldTypeString	50
21	integer	TRANSFORMER_UG_OBJECTID	Transformer Object ID		esriFieldTypeInteger	
22	image	Attachment	Attachment			

Appendix 15: Service Points

	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one EnabledDon	Enabled	Enabled	1	esriFieldTypeSmallInteger	
5	select_one SubtypeCD	SubtypeCD	Subtype	3	esriFieldTypeInteger	
6	text	FacilityID	Facility ID		esriFieldTypeString	20
7	text	Material	Material		esriFieldTypeString	20
8	text	StructureSize	Structure Size		esriFieldTypeString	20
9	text	StructureType	Structure Type		esriFieldTypeString	20
10	text	Manufacturer	Manufacturer		esriFieldTypeString	20
11	text	Model	Model		esriFieldTypeString	20
12	text	Comments	Comments		esriFieldTypeString	255
13	text	CreationUser	Creation User		esriFieldTypeString	50
14	dateTime	DateCreated	Date Created		esriFieldTypeDate	
15	text	LastUser	Last User		esriFieldTypeString	50
16	dateTime	DateModified	Date Modified		esriFieldTypeDate	
17	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
18	text	OWNER	Owner	City of Aspen	esriFieldTypeString	50
19	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString	50
20	image	Attachment	Attachment			

Appendix 16: Splice Vault

	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
1	type	name	label	default	bind::esri:fieldType	bind::esri:fieldLength
2						
3	geopoint	geometry	Geometry			
4	select_one Subtype	SubtypeCD	Subtype	4	esriFieldTypeInteger	
5	select_one PhaseDesignation	PhaseDesignation	Phase Designation	7	esriFieldTypeInteger	
6	text	FacilityID	Facility ID		esriFieldTypeString	20
7	text	FeederID	Feeder ID		esriFieldTypeString	20
8	integer	OperatingVoltage	Operating Voltage		esriFieldTypeInteger	
9	dateTime	InstallationDate	Installation Date		esriFieldTypeDate	
10	integer	NominalVoltage	NominalVoltage		esriFieldTypeInteger	
11	select_one Yes/No	ManuallyOperated	Manually Operated Indicator	Y	esriFieldTypeString	5
12	select_one SwitchMaxContinuousCurrent	MaxContinuousCurrent	Maximum Continuous Current	600	esriFieldTypeDouble	
13	select_one MaxOperatingVoltage	MaxOperatingVoltage	Maximum Operating Voltage	210	esriFieldTypeInteger	
14	select_one NormalStatus	NormalPosition_A	Normal Position - A	1	esriFieldTypeInteger	
15	select_one NormalStatus	NormalPosition_B	Normal Position - B	1	esriFieldTypeInteger	
16	select_one NormalStatus	NormalPosition_C	Normal Position - C	1	esriFieldTypeInteger	
17	select_one PresentStatus	PresentPosition_A	Present Position - A	1	esriFieldTypeInteger	
18	select_one PresentStatus	PresentPosition_B	Present Position - B	1	esriFieldTypeInteger	
19	select_one PresentStatus	PresentPosition_C	Present Position - C	1	esriFieldTypeInteger	
20	text	Normally_Open	Normally Open		esriFieldTypeString	50
21	text	SCADAControlID	SCADA Control ID		esriFieldTypeString	20
22	text	SCADAMonitorID	SCADA Monitor ID		esriFieldTypeString	20
23	text	PreferredCircuitSource	Preferred Circuit Source		esriFieldTypeString	20
24	select_one Yes/No	GangOperated	Gang Operated Indicator	N	esriFieldTypeString	5
25	text	Comments	Comments		esriFieldTypeString	255
26	text	CreationUser	Creation User		esriFieldTypeString	50
27	dateTime	DateCreated	Date Created		esriFieldTypeDate	
28	text	LastUser	Last User		esriFieldTypeString	50
29	dateTime	DateModified	Date Modified		esriFieldTypeDate	
30	text	OWNER	Owner	City of Aspen	esriFieldTypeString	50
31	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString	50
32	text	CONSTRUCTIONTYPE	Construction Type		esriFieldTypeString	50
33	image	Attachment	Attachment			

Appendix 17: Switch

	type	name	label	default	bind::esri:fieldType
1	type	name	label	default	bind::esri:fieldType
2					
3	geopoint	geometry	Geometry		
4	dateTime	DateCreated	Date Created		esriFieldTypeDate
5	text	LastUser	Last User		esriFieldTypeString
6	dateTime	DateModified	Date Modified		esriFieldTypeDate
7	select_one SubtypeCD	SubtypeCD	Subtype		esriFieldTypeInteger
8	select_one ElectricDeviceOperatingVoltage	OperatingVoltage	Operating Voltage	14	esriFieldTypeInteger
9	select_one PhaseDesignation	PhaseDesignation	Phase Designation		esriFieldTypeInteger
10	select_one Rated_kVA	Rated_kVA	Rated kVA		esriFieldTypeInteger
11	select_one model	Model_Make	Model/Make		esriFieldTypeString
12	select_one Construction_Status	ConstructionStatus	Construction Status	5	esriFieldTypeInteger
13	dateTime	InstallationDate	Installation Date		esriFieldTypeDate
14	text	Comments	Comments		esriFieldTypeString
15	select_one TransformerBankHighSideProtection	HighSideProtection	High Side Protection		esriFieldTypeString
16	text	LocationType	Location Type	SVC	esriFieldTypeString
17	text	OWNER	Owner	City of Aspen	esriFieldTypeString
18	text	OPERATINGCLASS	Operating Class	Distribution	esriFieldTypeString
19	text	CONSTRUCTIONTYPE	Construction Type	Underground	esriFieldTypeString
20	text	Secondary_Address_Location	Secondary Address/Location		esriFieldTypeString
21	text	SecondaryVoltage	Secondary Voltage		esriFieldTypeString
22	text	HighSideConfiguration	High Side Configuration		esriFieldTypeString
23	text	LowSideConfiguration	Low Side Configuration		esriFieldTypeString
24	text	LoadTapChangerIndicator	Load Tap Changer Indicator		esriFieldTypeString
25	decimal	FilledWeight	Filled Weight		esriFieldTypeDouble
26	text	SwitchType	Switch Type		esriFieldTypeString
27	decimal	AlternateX	Alternate - X		esriFieldTypeDouble
28	decimal	AlternateY	Alternate - Y		esriFieldTypeDouble
29	decimal	AlternateZ	Alternate - Z		esriFieldTypeDouble
30	text	AlternateSource	Alternate Source		esriFieldTypeString
31	text	FacilityID	Facility ID		esriFieldTypeString
32	text	CreationUser	Creation User		esriFieldTypeString
33	text	WorkOrderID	Work Order ID		esriFieldTypeString
34	integer	FeederInfo	Feeder Information		esriFieldTypeInteger
35	decimal	SymbolRotation	Symbol Rotation		esriFieldTypeDouble
36	image	Attachment	Attachment		

Appendix 18: Transformers